Mississippi Water Resources Research Institute
Annual Technical Report
FY 2010

Introduction

The Mississippi Water Resources Research Institute (MWRRI) provides a statewide center of expertise in water and associated land use and serves as a repository of knowledge for use in education, research, planning, and community service.

The MWRRI goals are to serve public and private interests in the conservation, development, and use of water resources; to provide training opportunities in higher education whereby skilled professionals become available to serve government and private sectors alike; to assist planning and regulatory bodies at the local, state, regional, and federal levels; to communicate research findings to potential users in a form that encourages quick comprehension and direct application to water related problems; to assist state agencies in the development and maintenance of a state water management plan; and to facilitate and stimulate planning and management that:

• Deals with water policy issues, • Supports state water agencies' missions with research on problems encountered and expected, • Provides water planning and management organizations with tools to increase efficiency and effectiveness.

Research Program Introduction

The Mississippi Water Resources Research Institute (MWRRI) conducts an annual, statewide competitive grants program to solicit research proposals. Proposals are prioritized as they relate to the research priorities established by the MWRRI Advisory Board and by their ability to obtain Letters of Support or External Cost Share from non−federal sources in Mississippi. The MWRRI's External Advisory Board then evaluates all proposals. Based on the most current list of research priorities, these would include: water quality, surface and groundwater management, water quality management and water resources development, contaminant transport mechanisms, wetlands and ecosystems, groundwater contamination, as well as other issues addressing coastal and marine issues linking water associations through the state, and institutional needs that include capacity building and graduate student training.

Monitoring and Modeling Water Pollution in Mississippi Lakes

Basic Information

Title:	Monitoring and Modeling Water Pollution in Mississippi Lakes
Project Number:	2008MS81B
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Focus Category:	Water Quality, Surface Water, Recreation
Descriptors:	None
Principal Investigators:	Cristiane Q. Surbeck

Publications

1. Quarterly status reports 2008-2009 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Kinnaman, A. and C.Q. Surbeck. 2009. "The use of microcosm studies to determine the effect of sediments and nutrients on bacteria in lake water." 2009 Mississippi Water Resources Conference, August 5-7, 2009, Tunica, MS in Proceedings, p. 140. http://www.wrri.msstate.edu/pdf/2009_wrri_proceedings.pdf
3. Kinnaman, A. 2009. The use of microcosm studies to determine the effect of sediments and nutrients on bacteria in lake water," a thesis at the University of Mississippi, University, MS, July 2009, 113 pgs.
4. Surbeck, C.Q. 2009. Final technical report on "Monitoring and Modeling Water Pollution in Mississippi Lakes: The Use of Microcosm Studies to Determine Die-Off of Fecal Pollutants," to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 27 pgs.

Monitoring and Modeling Water Pollution in Mississippi Lakes: The Use of Microcosm Studies to Determine Die-Off of Fecal Pollutants

A Final Project Report to the
Mississippi Water Resources Research Institute

Conducted by
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September 30, 2009

1 Abstract

The aim of this research is to determine the die-off rates of total coliform and *Escherichia coli* bacteria in lake and tributary waters in order to provide improved parameters for mathematical modeling of fecal pollution. Two field and laboratory studies were performed. One study was used to sample and monitor fecal pollution in two creeks that are tributaries to Sardis Lake. A second study used a discharge point of a tributary into Lower Sardis Lake, Thompson Creek, to better understand the concentrations and decay rates of total coliforms and *E. coli* in the lake water column and in the lake sediment. In both studies, samples were collected and tested for total coliforms, *E. coli*, dissolved oxygen (DO), temperature, nitrates, phosphate, and phenols. In both studies, microcosms were created with creek water. Samples from each microcosm were collected approximately every 12 hours for two days and 24 hours for the subsequent five days. Bacteria concentrations from the microcosms were plotted against time, and first-order decay constants were obtained. In the second study, another six microcosms (for a total of seven microcosms) were created and monitored in the laboratory. The seven microcosms consisted of (1) lake water, (2) lake water and sediment, (3) lake water and sterilized sediment, (4) sterilized lake water and sediment, (5) sterilized deionized water and sediment, (6) sterilized lake water, and (7) sterilized deionized water and sterilized sediment. *E. coli* decay rates were found to be lower when sediment was present.

2 Budget

2.1 Budget Requested

The budget requested from Federal funds, was $7500 (direct costs), and the non-Federal matching was $15,000 by the University of Mississippi in the form of salary, fringe benefits, and indirect costs.

2.2 Budget Expended

The budget expended from Federal funds, was $7431.59 (direct costs), and the non-Federal matching was $15,958.70 by the University of Mississippi in the form of salary, fringe benefits, and indirect costs. The breakdown of expended funds is shown in Table 2.1.

Table 2-1. Summary of Budget Expended.

Cost Category	Federal ($)	Non-federal (matching by UM) ($)	Total ($)
1. Salaries and wages	$2,400.00	$6,328.00	$8,728.00
2. Fringe benefits	$3.58	$2483.67	$2487.25
3. Supplies	$5,028.01	0	$5,028.01
4. Total direct costs	0	0	0
5. Indirect costs	0	$7147.03	$7147.03
6. Total estimated costs	$7,431.59	$15,958.70	$23,390.29

3 *Students Involved, Presentations, and Publications*

Five students were involved in this project. See Table 3.1 for a description.

Table 3-1. Students involved in project.

Student Name	Major	Class	Involvement
Alison Kinnaman	Environmental Engineering	Master's	Project Parts A and B (thesis is Part B)
John Mark Henderson	Civil Engineering	Senior	Project Part A
Keah Y. Lim	Civil Engineering	Senior	Project Parts A and B
Casey Wilson	Chemical Engineering	Junior	Project Part A
Shannon Wilson	Environmental Engineering	Master's	Project Part A

Project Part A was conducted as a Special Topics course in which the five students were enrolled. The course Projects in Surface Water Quality Modeling (Engr 596) was conducted in Fall 2008. During the course, academic work was conducted on surface water quality modeling, following the textbook *Surface Water Quality Modeling*, by Steven Chapra. About half of the coursework was field, laboratory, and data analysis work to conduct Part A of the study. In this study, two creeks were sampled, Davidson and Toby Tubby, from urban and rural areas leaving the general vicinity of Oxford, MS, and emptying into Sardis Lake.

Student Alison Kinnaman used Part B of this study as her thesis topic. She graduated in August 2009, and her thesis, "Using Microcosm Studies to Determine the Effect of

Sediments and Nutrients on Bacteria in Lake Water" has been submitted to the Graduate School of the University of Mississippi. Her work is summarized in Part B of this report and was presented at the 2009 Mississippi Water Resources Conference. It is anticipated that the combined work described in Parts A and B of this report will be written as a manuscript for submission in a peer-reviewed journal.

4 Motivation for Project

Lakes are generally understudied bodies of water due to the popularity of coastal beaches (USEPA 2009). This research aims to better understand these ignored recreational waters. Sardis Lake, a large reservoir in northern Mississippi, is an important social and economic resource. This lake is the focus of this project on the persistence of fecal indicator bacteria in recreational waters. To conduct this study, tributaries to the lake were selected as sampling sites in order to represent pollutant input.

The research goal is to determine mechanisms of die-off and survival of fecal indicator bacteria in water that is located in tributaries and in an embayment between Thompson Creek and Lower Sardis Lake in north Mississippi. To this end, several sampling events and microcosm studies were conducted. The primary mechanisms studied were the die-off rates of *E. coli* in water and suspension of *E. coli* from sediments to the water column.

5 Project Part A: The Use of Microcosm Studies to Determine Fecal Indicator Bacteria Decay Rates in Tributary Creeks to Sardis Reservoir

5.1 Objectives

The objective of the Part A study on tributary creeks to Sardis Reservoir as to calculate kinetic rate constants of die-off of fecal indicator bacteria in Davidson Creek and Toby Tubby Creek, which are part of an urban and sub-rural watershed.

5.2 Field Site

Sardis Lake is a dammed reservoir on the Little Tallahatchie River located between the Little Tallahatchie River's two impaired segments. The City of Oxford, Mississippi, lies south of Sardis Lake and the cities runoff enters Davidson Creek on the north side of the city. Davidson Creek and Toby Tubby Creek are located in a farming and forested sub-watershed and are classified as an irregular open channel flow body. The flow velocities of the four different sample locations varied substantially from no flow at all at location DAV1 to a much greater flow at location TT2. See sample locations in Figure 5-1.

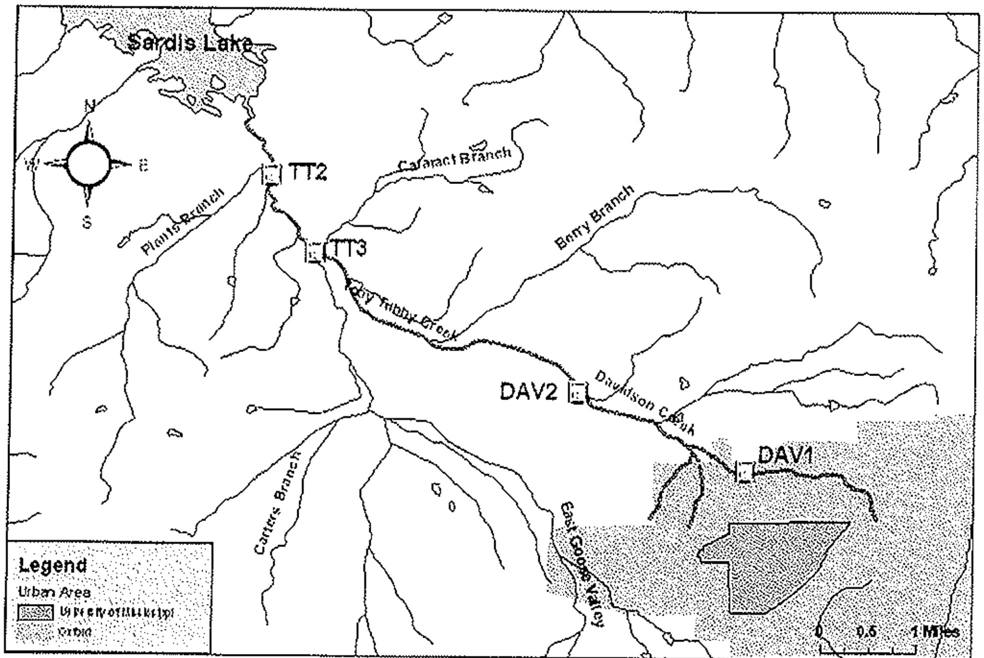


Figure 5-1. Sample locations on Toby Tubby Creek and Davidson Creek.

5.2 Materials and Methods

5.2.1 Field Locations

The sampling locations were the following:

1. DAV1 on Davidson Creek adjacent to Lamar Park on College Hill Road (34° 21.851'N, 89° 32.097'W;
2. DAV2 on Davidson Creek as it flows under Anchorage Road (34° 23' 24.59" N, 89° 33' 59.21" W);
3. TT3 on Toby Tubby Creek as it crosses County Road 105 (34° 25.321'N, 89° 36.834'W); and
4. TT2 on Toby Tubby Creek where it crosses Highway 314 (34° 25' 19.63" N, 89° 36' 51.3" W).

5.2.2 Water Quality Analyses

Several water quality analyses were performed during the sampling events conducted on September 17, September 18, September 22, and October 20, 2008. Both water samples and microcosms were examined for total coliform, *E. coli*, nitrate, nitrite, phenols, phosphate, dissolved oxygen (DO), and dissolved organic carbon (DOC).

The bacteria were cultured by a defined-substrate method called Colilert (IDEXX Laboratories, Maine). The bacteria (total coliform and *E. coli*) were counted and recorded as Most Probable Number per 100 mL (MPN/100 mL). The water samples were tested for the following parameters: dissolved oxygen, nitrite, nitrate, phosphate, and phenols. Each of these parameters was analyzed by colorimetry using vacu-vials and CHEMetrics photometer (CHEMetrics, Inc., Calverton, Virginia). Nitrite was analyzed for only in the September 17 samples because the results were below the detection limit.

DOC analysis was carried out by filtering 80-mL of sample water through 0.45-micron filters. Next, two 40-mL vials, preserved with hydrochloric acid, were filled. The vials were then placed in a refrigerator until the samples were sent to Environmental Testing and Consulting, Inc. (ETC) in Memphis, TN. A chain of custody record was also sent with the samples. In order to send the materials, a cooler was filled with ice and the sample vials. The chain of custody identified the sample identification numbers, the number of samples, date the samples were taken, times the samples were taken, the type of sample, and matrix, along with what test is required (EPA Method 415.1).

5.2.3 Microcosm Studies

Two microcosm studies were conducted. Both studies included water samples from DAV1, DAV2, TT2, and TT3, but the incubation methods employed were different. The first study involved a stationary incubator with an internal temperature of 35°C, while the second study utilized a shaker incubator at a constant temperature of 30°C. Also, some of the sampling rounds for the second study incorporated different dilutions, as will be discussed further below. Other than this, the set-up and sampling procedures for the two microcosm studies were identical.

First Microcosm Study

On September 22, 2008 water samples were collected from the following locations: DAV1, DAV2, TT2, and TT3. In the lab, bacteria were cultured as explained above. The CHEMetrics instrument was used to determine the concentrations of nitrate, phenols, and phosphates in parts per million (ppm). Initial analyses were conducted on the water in the sample bottle.

After completing these tests, the microcosms were set up. A microcosm study is a study in which one examines water samples over time in an incubator. Each sample represents the location of the sample taken. In order to set-up the microcosms, 500 mL of each sample were poured into separate sterilized Erlenmeyer flasks. A foam stopper was placed in each flask, and the flasks were labeled and placed in a stationary incubator at a temperature of 30°C. We chose a 500-mL sample because we needed enough water to last 5 days while sampling every 12 hours, to analyze nitrate, phosphate, and phenols another time and to send two dissolved organic carbon (DOC) samples to ETC Laboratory in Memphis, TN. The sampling times were roughly 7 AM and 7 PM every day. The water samples were obtained using sterile techniques and then tested in duplicate for total coliform and *E. coli* using the Colilert method. In order to sample a microcosm in a sterile manner, the stopper was removed and the opening of the flask was passed through the flame of a Bunsen burner to remove any contaminants. Then the correct amount of water was pipetted from the flask and placed in dilution vials. For the first microcosm study, 10 mL of water were removed from the flask each time and were placed in a

90 mL dilution vial to make a 10% dilution. Two aliquots of water were removed from each microcosm at each sampling time so that the bacteria test could be performed in duplicate. After sampling, each microcosm flask was sterilized in the flame and promptly stoppered. The flasks were then returned to the incubator until the next sampling event.

Second Microcosm Study

On October 20, 2008 another round was sampling was conducted at the four locations. Water quality analysis and microcosms were set up as described above. The microcosms were sampled every 12 hours for 5 days, and the same procedures were followed as described above.

5.3 Results

5.3.1 Inventory of Sample Results

The results of the initial samples are recorded in Table 5-1. The highest pollutant concentration was found at site DAV 1. The lowest pollutant concentration was found at site DAV 2.

Table 5-1. Inventory of initial sample results.

Date	Site	Total coliform (MPN/100 mL)	*E. coli* (MPN/100 mL)	DOC (mg/L)	DO (mg/L)	NO3 (mg/L)	Phenols (mg/L)	PO4 (mg/L)
9/17/2008	DAV1	24196	477	4.13	3.13	0.202	0.43	0.2
	TT2	24196	465	-	8.33	0.06	0.43	0.165
9/18/2008	DAV2	818	-	<1	8.67	0.4	0.31	0.15
9/22/2008	DAV1	21923	332	4.18	-	0.341	0.539	0.28
	DAV2	19863	651	1.39	-	0.54	0.368	0.09
	TT2	18553	756	3.07	-	0.33	0.433	0.16
	TT3	18553	508	2.75	-	0.24	0.504	0.16
10/20/2008	DAV1	23088	355	10.3	5.4	0.22	0.61	0.7
	DAV2	7715	399	3.41	8.97	0.426	0.24	0.035
	TT2	9006	356	3.77	8.995	0.29	0.28	0.09
	TT3	17795	202	4.6	8.4	0.24	0.32	0.027

5.3.2 Results of First Microcosm Study

Figures 5-2 and 5-3 show the graphs of the natural logarithm of the total coliform and *E. coli* concentrations versus time, respectively, for the first microcosm study. The graphs illustrate the net decrease in bacteria concentrations with time when a sample is isolated from its environment.

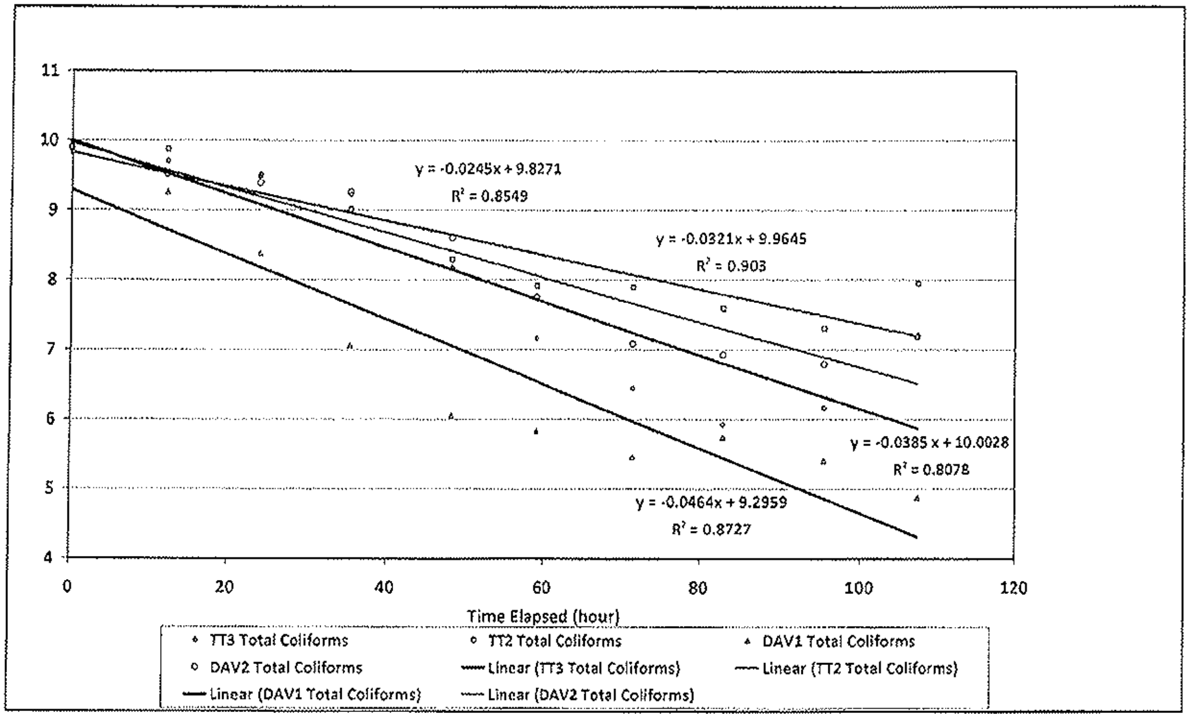


Figure 5-2. Ln(total coliform concentration) versus elapsed time for the first microcosm study. Listed equations are linear regression equations, along with R^2 values.

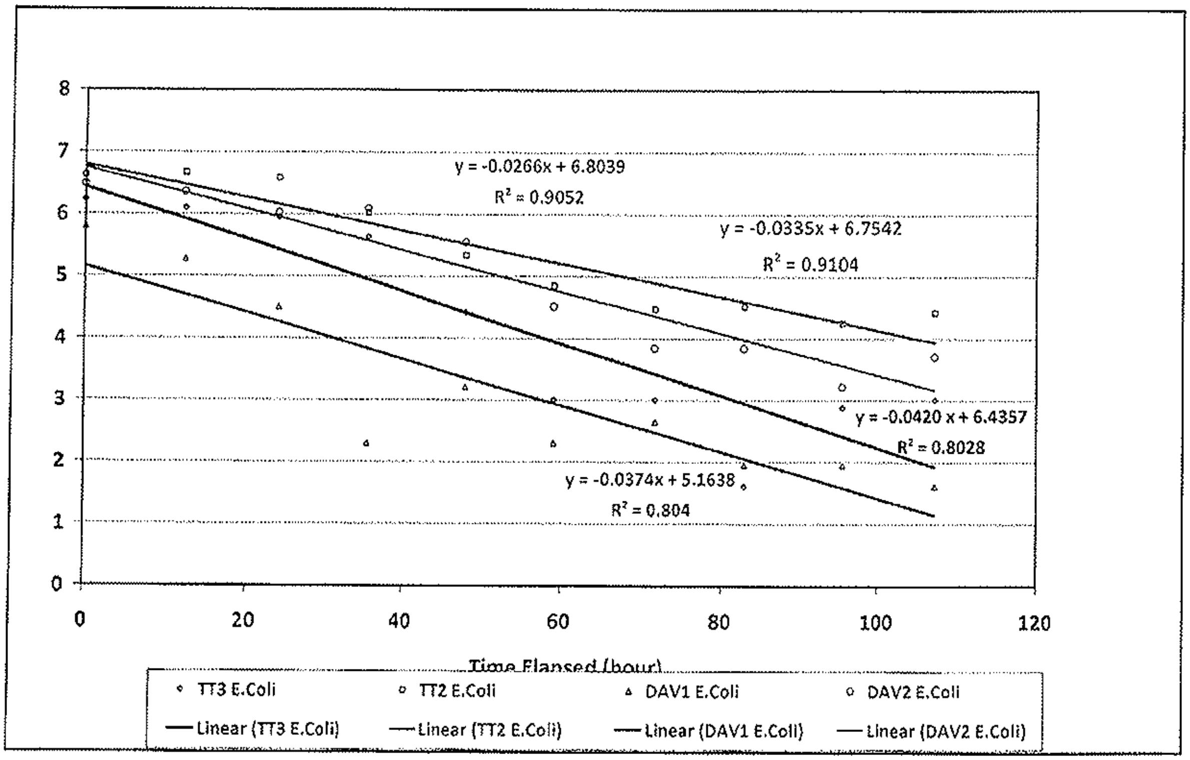


Figure 5-3. Ln(*E. coli* concentration) versus elapsed time for the first microcosm study. Listed equations are linear regression equations, along with R^2 values.

5.3.3 Results of Second Microcosm Study

Figures 5-4 and 5-5 show the graphs of the natural log of the total coliform and *E. coli* concentrations versus time, respectively, for the second microcosm study. The graphs illustrate the net decrease in bacteria concentrations with time when a sample is isolated from its environment.

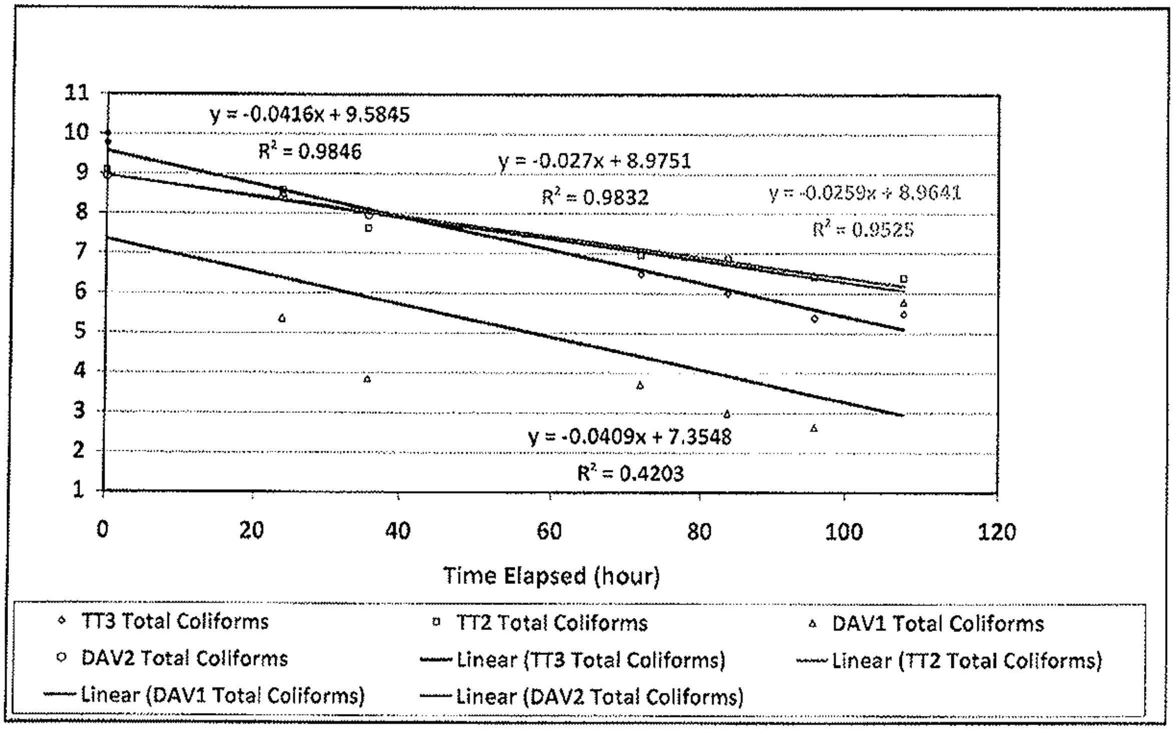


Figure 5-4. Ln(total coliform concentration) versus elapsed time for the second microcosm study. Listed equations are linear regression equations, along with R^2 values.

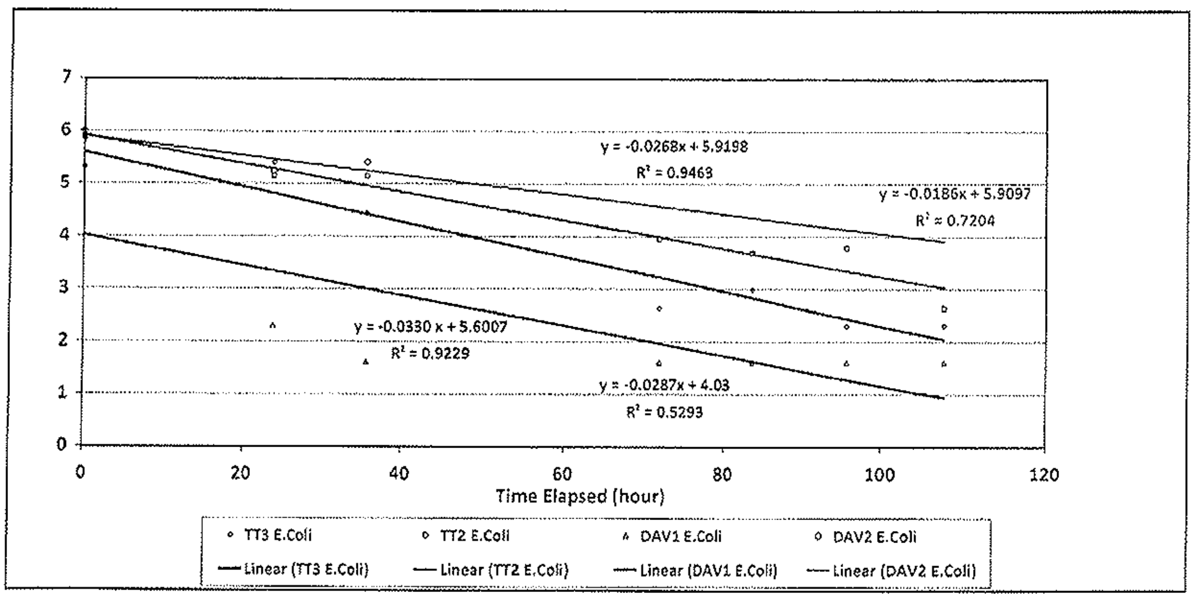


Figure 5-5. Ln(*E. coli* concentration) versus elapsed time for the second microcosm study. Listed equations are linear regression equations, along with R^2 values.

5.3.4 *Kinetic Rate Constants*

The kinetic rate constants obtained for the decay of bacteria in the microcosms are summarized below. These values were obtained by the integral method. For the first microcosm study, concentration, ln(concentration), and 1/concentration were all graphed vs. time elapsed. Concentration vs. time represents a zero-order reaction, ln(concentration) vs. time represents a first-order reaction, and (1/concentration) vs. time represents a second-order reaction. A linear trend line was fit to each of these graphs. The trend lines for the first-order reactions had the highest R^2 value, so the reactions were assumed to be first order. The decay constants are the slopes found from the trend lines. For analysis of the second microcosm study, all reactions were assumed to be best modeled by first-order reactions and the decay constants were obtained as described from the graph of ln(concentration) vs. time.

Table 5-2. Kinetic rate constants for fecal indicator bacteria in water from Davidson Creek and Toby Tubby Creek.

		Total Coliform		*E. coli*	
	Site Name	Decay Constant, k (hr^{-1})	R^2	Decay Constant, k (hr^{-1})	R^2
First Microcosm Study	TT2	0.0245	0.8549	0.0266	0.9052
	TT3	0.0385	0.8078	0.0420	0.8028
	DAV1	0.0464	0.8727	0.0374	0.8040
	DAV2	0.0321	0.9030	0.0335	0.9104
Second Microcosm Study	TT2	0.0259	0.9526	0.0268	0.9482
	TT3	0.0416	0.9846	0.0330	0.9236
	DAV1	0.0408	0.4202	0.0287	0.5293
	DAV2	0.0270	0.9832	0.0186	0.7231

6 *Project Part B: The Use of Microcosm Studies to Determine the Effect of Sediments and Nutrients on Fecal Indicator Bacteria in Lake Water*

6.1 Research Objectives

The research objectives were to determine how *E. coli* decay rates in lake water are affected by sediments. The hypothesis is that the presence of sediments increases the persistence of the fecal indicator bacteria (FIB) in lake water. The FIB groups studied in this research are total coliforms and *Escherichia coli*. The information on die-off rates and on *E. coli* dependence on sediment is useful to determine parameters for numerical modeling in lakes. This research may also have an impact on lake water quality management.

Many computer models, including Soil & Water Assessment Tool (SWAT), Hydrologic Simulation Program-Fortran (HSPF), and the National Center for Computational Hydroscience and Engineering's CCHE-2D, use first-order decay models for fecal coliforms in surface waters for predicting water quality both spatially and temporally. These models only perform well if the parameters for decay are accurate. In addition, they often do not consider the impact of sediment on the decay rates of bacteria. Therefore, this research is innovative because it uses a methodology to determine decay rates that are influenced by sediment.

The results of this research also have implications for lake water quality management. The results from this study could indicate whether bacteria concentrations are above or below U.S. Environmental Protection Agency criteria, which could indicate that the sampling location might need special attention.

6.2 Materials and Methods

6.2.1 Sample Collection

Sediment and water samples were collected where Thompson Creek feeds into the lower Sardis Lake in northern Mississippi. The water and sediment samples were collected in Nalgene bottles (Nalgene Company, Rochester, NY) previously autoclaved at 121°C in an EZ 9 autoclave (2340EA, Tuttnauer, Hauppauge, NY). Sediment samples were collected with 2-inch by 4-inch aluminum sediment core sleeves previously autoclaved at 134°C in an EZ 9 autoclave. The sleeve was approximately half-way filled so that the sediment would represent the top 5 cm, which contains the most recent nutrient influx. Water samples were collected from the water surface, and sediment samples were collected from the embayment bank above the water surface. All samples were cooled and transported to the laboratory at the University of Mississippi.

Four sampling events were conducted on the following dates: July 11, 2008, August 19, 2008, January 7, 2009, and April 10, 2009. Figure 6-1 is a photograph of the sample collection site.

Figure 6-1. Sample collection at Thompson Creek's inlet to the lower Sardis Lake.

Microcosm set up began once the samples were brought to the laboratory.

6.2.2 Pre-Microcosm Preparation (sediment measurement, separation of bacteria, autoclaving and water filter-sterilization)

First, the sediment was mixed to make a homogeneous soil matrix in order to provide each applicable microcosm with a representative sediment sample. This was accomplished by putting the sediment from the Nalgene bottles in an aluminum pan and mixing. Afterwards, approximately 500 cm^3 (bulk) of sediment was autoclaved at 121°C to eliminate the bacteria for two of the microcosms. Second, bacteria were extracted from the unsterilized sediment within three hours of collection. This was done following a procedure adapted and modified from Craig et al. 2002 and Jeong et al. 2005. A 0.1% peptone solution was prepared by dissolving 0.5 g of peptone in 400 mL deionized (DI) water. Then more deionized water was added to increase the volume to 500 mL.

Twelve and a half grams (wet weight) of sediment were weighed using sterilized equipment and transfer media (beaker, centrifuge tube, and spatula). In addition, the dry weight of sediment was determined by weighing 2 grams of wet sediment in an aluminum weighing dish (Fisher Scientific, Pittsburgh, PA) and placing the dish with sediment in a Thelco oven (Precision Scientific Co., Chicago, IL.) for 24 hours at 110°C and re-weighing the remaining sediment.

The 12.5 g of sediment were added to a sterile 50-mL centrifuge tube (Fisher Scientific, Pittsburgh, PA), then suspended in 37.5 mL of 0.1% peptone solution. The tube was closed and hand shaken for one minute.

The sediment-peptone mixture was centrifuged at 2500 rpm for 10 minutes in a MARATHON 3200 (Fisher Scientific, Pittsburgh, PA) centrifuge. This was done to separate the bacteria from the sediment to a liquid supernatant.

6.2.3 *Bacteria Analysis for Sediment*

Once the supernatant was retrieved, 1 mL of it was added to a dilution vial (Hardy Diagnostics, Santa Maria, CA) filled with 99 mL of deionized water and Colilert powder (Idexx Laboratories, Inc., Westbrook, Maine) to fill the vial to a total of 100 mL. Two dilution vials were filled with one sample each of the supernatant so that the geometric means of the results could be calculated. The dilution vials were then capped and shaken until the Colilert was dissolved. Next, the solutions were poured into Quanti-Trays (Idexx Laboratories, Inc., Westbrook, Maine) and sealed using a Quanti-Tray Sealer Model 2X (Idexx Laboratories, Inc., Westbrook, Maine), then incubated at 35 degrees Celsius in a Presision (Precision Scientific, Inc., Winchester, VA) incubator for 24 hours. The Quanti-Tray wells indicating total coliforms and *E. coli* were counted, converted to units of most probable number (MPN) per 100 grams, and recorded. Based on Jeong 2005's formula, the sediment bacteria concentration (Cs) in units of MPN per 100 grams was calculated as follows:

$$C_s = \frac{C_t \times 37.5\ mL \times 100}{W_s r}$$

where C_t is the bacteria concentration calculated from the 1 mL of supernatant, W_s (grams) is the wet weight of sediment suspended in the 0.1% peptone solution, and r is the sediment's dry-to-wet weight ratio.

6.2.4 *Bacteria Analysis for Water*

Bacteria analysis was performed on water pre-microcosm experiments using the same technique described in the Bacteria Analysis for Sediment section, with the following exceptions. Depending on previous weather conditions, either 1 mL or 10 mL of water sample was pipetted into a dilution vial (in the case of recent rain or no previous rain, respectively). Each sample was analyzed in duplicate. The concentration was determined by converting the Quanti-Tray well counts to MPN per 100 mL using the chart issued by Idexx Corporation.

6.2.5 *Microcosm Preparation*

Following the sediment preparation and lake water bacteria analysis described above, seven microcosms were made in 500-mL flasks: Microcosm 1 (water), Microcosm 2 (water and sediment), Microcosm 3 (water and sterilized sediment), Microcosm 4 (sterilized water and sediment), Microcosm 5 (sterilized deionized water and sediment), Microcosm 6 (sterilized water control), Microcosm 7 (sterilized DI water and sterilized sediment control). The following is a detailed description of each microcosm.

Microcosm 1. Composed of water, this microcosm is used to monitor the kinetic rate constant of total coliforms and *E. coli* due to die-off without the effect of nutrients and bacteria associated with sediment. See Figure 6-2, Microcosm 1, for a schematic showing bacterial die-off in the water.

Microcosm 2. Composed of water and sediment, this microcosm is used to monitor the kinetic rate constant of total coliforms and *E. coli* in water under the effect of nutrients and bacteria associated with sediment. See Figure 6-2, Microcosm 2, for a schematic showing bacterial die-off in water and sediment, and bacterial and nutrient suspension from sediment to water.

Microcosm 3. Composed of water and sterilized sediment, this microcosm is used to monitor the kinetic rate constant of total coliforms and *E. coli* with the effect of nutrients, but not bacteria, associated with sediment. See Figure 6-2, Microcosm 3, for a schematic showing bacterial growth in water, and nutrient suspension from sediment to water.

Microcosm 4. Composed of sediment and sterilized water, this microcosm is used to monitor the kinetic rate constant of total coliforms and *E. coli* in water associated with sediment but without the effect of bacteria from the water. See Figure 6-2, Microcosm 4, for a schematic showing bacterial die-off in sediment, and bacterial and nutrient suspension from sediment to water.

Microcosm 5. Composed of sediment and sterilized deionized water, this microcosm is used to monitor the kinetic rate constant of total coliforms and *E. coli* in water associated with sediment without the effect of bacteria and nutrients from the water. See Figure 6-2, Microcosm 5, for a schematic showing bacterial die-off in sediment, and bacterial and nutrient suspension from sediment to water.

Microcosm 6. Composed of sterilized water, this microcosm is used as a control to monitor whether filter sterilizing the water was successful. See Figure 6-2, Microcosm 6, for a schematic showing nutrients in water.

Microcosm 7. Composed of sterilized DI water and sterilized sediment, this microcosm is used as a control to monitor whether autoclaving the sediment and filter sterilizing the DI water were successful. See Figure 6-2, Microcosm 7, for a schematic showing nutrient suspension from sediment to water.

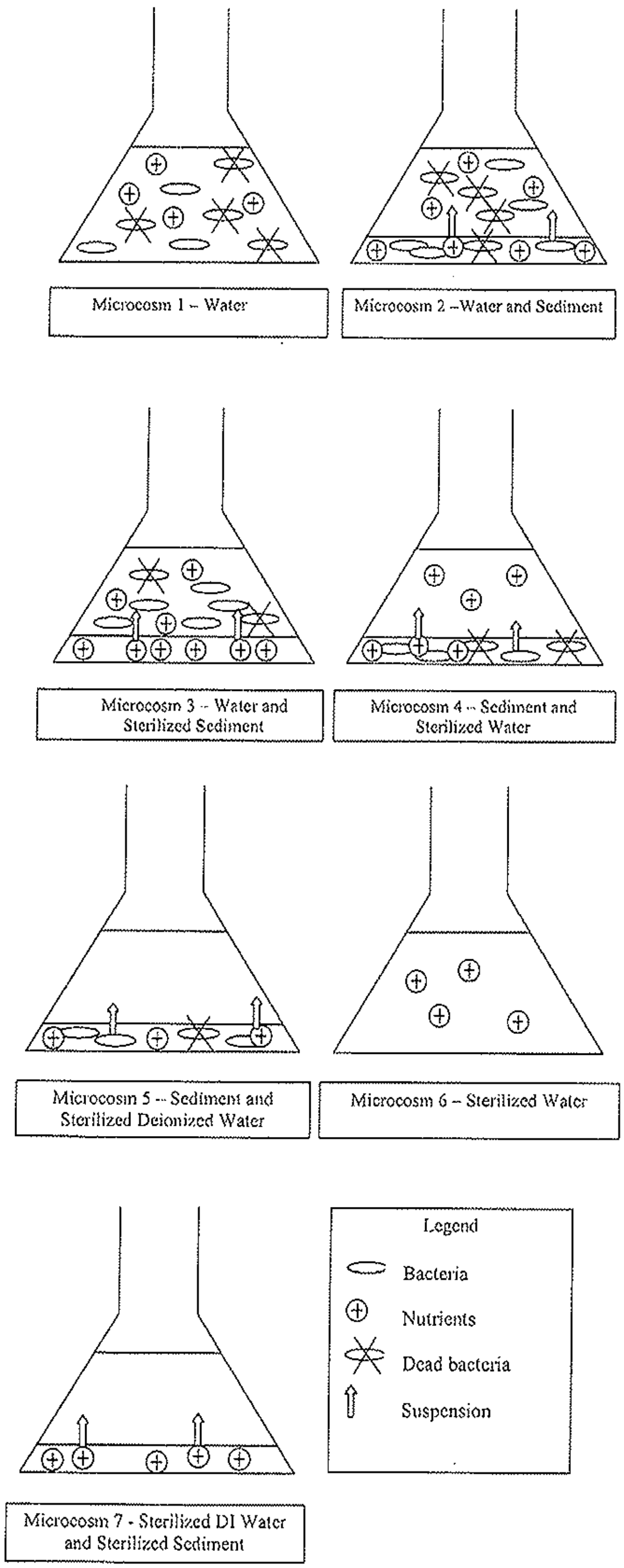


Figure 6-2. An illustration of the mechanisms occurring in Microcosms 1 through 7.

Each sediment-water microcosm consisted of approximately 200 grams of sediment and 300 to 500 mL of water, depending on the microcosm study. The microcosms of water alone had a known volume of aqueous solution, approximately 230 to 500 mL. Water was sterilized using filter sterilization with a 0.22 micron filter (Model number 8532, Corning, Corning, NY). The microcosms were incubated at 30 degrees Celsius in a shaker incubator (Classic C24, New Brunswick Scientific, Edison, NJ) at 60 revolutions per minute, as seen in Figure 6-3.

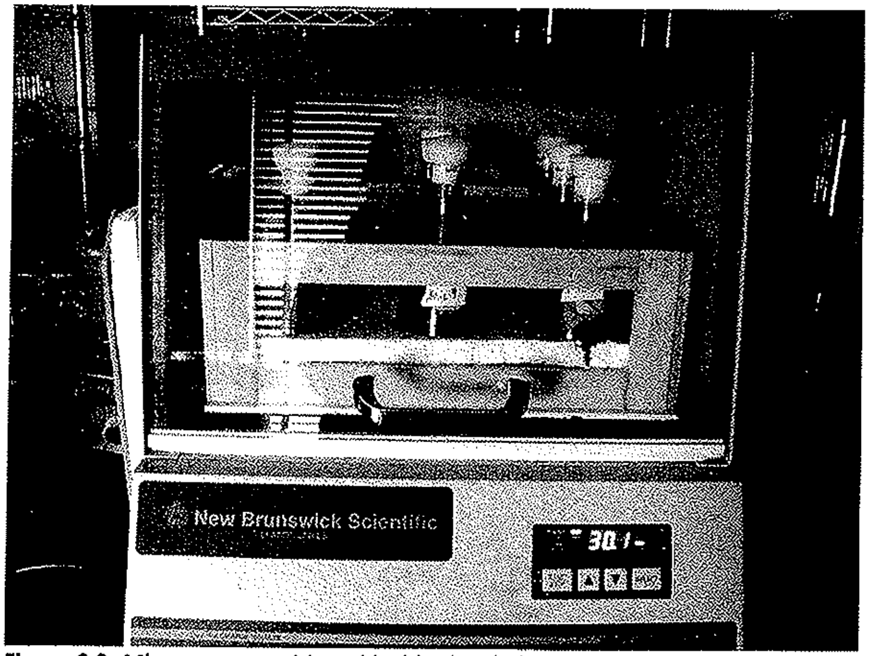


Figure 6-3. Microcosms positioned inside the shaker incubator.

6.2.6 *Microcosm Monitoring*

Water samples were collected from the microcosms at twelve-hour intervals in the first two days and at 24 hour intervals for the next five days. Each sample was analyzed following the procedures described above in the section Bacteria Analysis for Water (6.2.4). A total of 8 rounds of microcosm sampling were conducted. After the final round of sampling, the sediment from microcosms 2 to 5 were also tested following the procedures described above.

Depending on the previous bacteria reading, dilutions were either 1 mL sample: 99 mL water or 10 mL sample: 90 mL water. If previous bacteria concentrations were high, dilutions were 1% (1 mL); if previous bacteria concentrations were low, dilutions were 10% (10 mL).

6.2.7 *Data Analysis*

Data analysis was performed on all the water quality data. To determine the decay rate constants for bacteria in the microcosms, a graph of the natural log of the concentration vs.

time was created and a trendline was fitted to the data. Decay rate constants (k) were found using the linear trendline's slope value.

To determine a possible relationship between the sediment-water ratio, nutrients, and bacteria concentrations, Spearman's rank correlations were performed. Because Microcosms 1 and 2 differed only due to the sediment in Microcosm 2, it was assumed the concentration difference between them could be attributed to the sediment. Because Microcosms 4 and 5 differed due to the nutrients in the water in Microcosm 4, it was assumed the concentration difference between them could be attributed to the nutrients. Because Microcosms 2 and 4 differed due to the bacteria in the water in Microcosm 2, the concentration difference between them could be attributed to the bacteria. Because Microcosms 2 and 5 differed due to the bacteria and nutrients in the water in Microcosm 2, the concentration difference between them could be attributed to the bacteria and nutrients.

The sediment-water ratio was noted each time a water sample was taken and, for comparability, was used in the analysis up to the point where the ratio between microcosms differed only by one-hundredth of a point.

6.3 RESULTS

6.3.1 Water Quality Analyses

The initial concentrations of total coliforms and *E. coli* ranged between 8,177 – 33,718 MPN/100mL and 381–913 MPN/100mL, respectively. Nutrient concentrations ranged between 2.95 – 7.64 mg/L for dissolved organic carbon (DOC), 0.19 – 0.34 mg/L nitrate as N, 0.33 and 0.53 mg/L phosphate, 6.77 – 12.14 mg/L for dissolved oxygen (DO), and 0.59 -1.29 mg/L for phenols.

6.3.2 Bacteria Decay Rates

Four sampling events were conducted in which bacteria data were gathered and analyzed, and decay rate constants were found using the slope value of a linear trendline. Bacteria concentrations vs. time was plotted for Microcosms 1, 2, 4, and 5 by taking the geometric mean of the duplicate samples for each round and incorporating those data in an Excel graph. Microcosms 6 and 7 were excluded from the graphs because there were no bacteria present. Microcosm 3 was excluded from the graphs because it experienced bacterial growth and was, therefore, not applicable to the particular study of decay rates. However, this microcosm will be addressed in section 6.4.

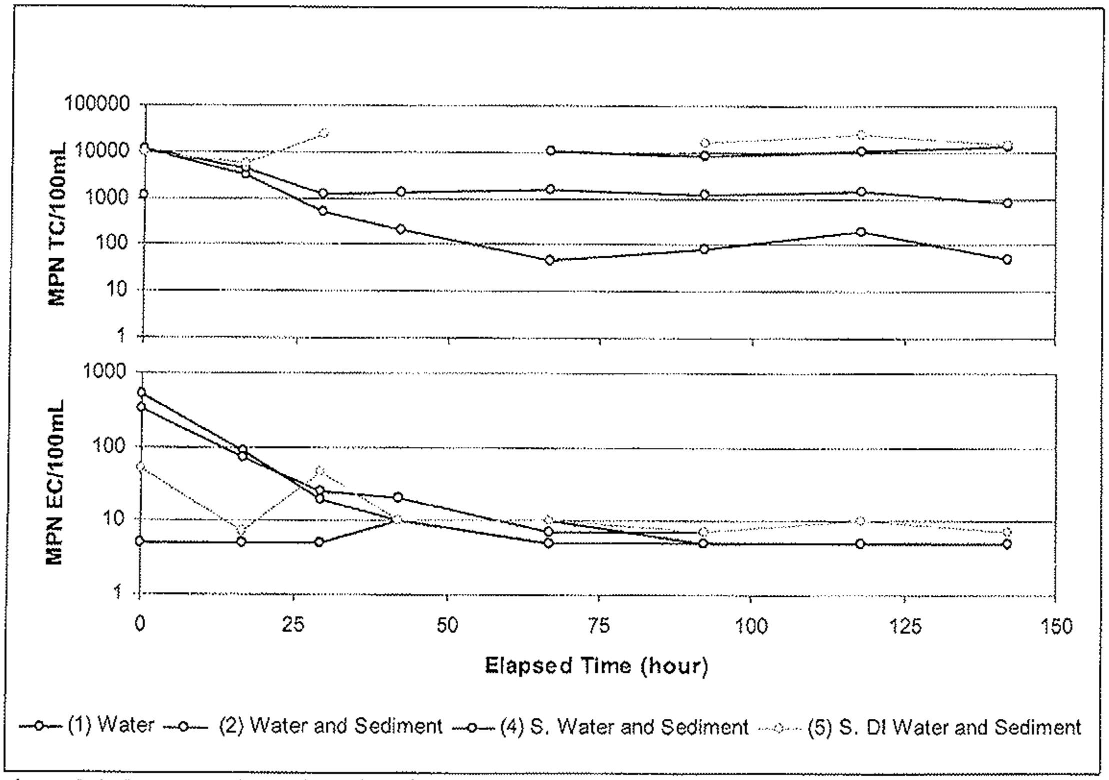


Figure 6-4. Concentrations of total coliforms and *E. coli* versus elapsed time during Study 1 (July 11, 2008). Numbers in parentheses indicate microcosm numbers.

Figure 6-4 shows that in Study 1, the total coliform and *E. coli* concentrations decreased faster in Microcosms 1 and 2. The total coliforms in Microcosms 4 and 5 increased; missing data points indicate concentrations that were above the method's upper detection limit. This bacterial growth could be attributed to many factors. One consideration is that the environments of Microcosms 4 and 5 are more conducive to growth because the bacteria concentration was reduced by filtration. Therefore, the bacterial population was initially below carrying capacity. Another explanation could be that the concentration of waste products will reach toxic levels sooner in Microcosms 1 and 2 because of the lower initial microorganism populations in Microcosms 4 and 5. Also, the nutrient concentrations could limit the amount of growth. The nutrient concentration in Microcosm 1 would be limited due to water being the sole source of nutrients. The nutrient concentration could possibly increase in Microcosm 2 due to sediment as a possible nutrient source. However, the bacteria in Microcosms 4 and 5 are less limited by nutrients because they do not compete with other organisms. *E. coli* concentrations follow a similar pattern of decay in Microcosms 4 and 5.

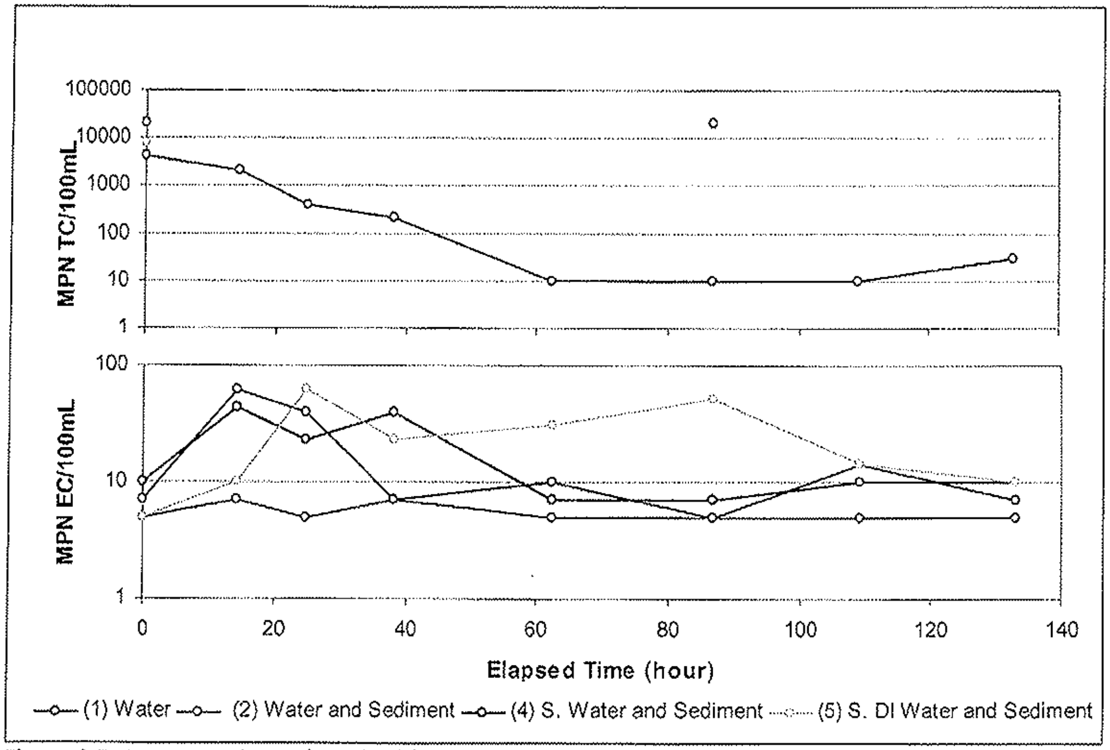


Figure 6-5. Concentrations of total coliforms and *E. coli* versus elapsed time during Study 2 (August 19, 2008).

Figure 6-5 shows that in Study 2, the concentrations in Microcosms 2, 4 and 5 were too large to be identified. This may be attributed to the estimated high DOC concentration in the initial water sample. Although the initial water DOC was not measured, it was assumed to be high based on the typical occurrence of the ending DOC concentrations being lower than the initial measurement; the final concentrations were high compared with the other studies.

All of the *E. coli* concentrations, excluding in Microcosm 1, increased in the beginning, then tapered off, except for Microcosm 5, which persisted longer than the others. These increases are also thought to be due to the DOC concentration.

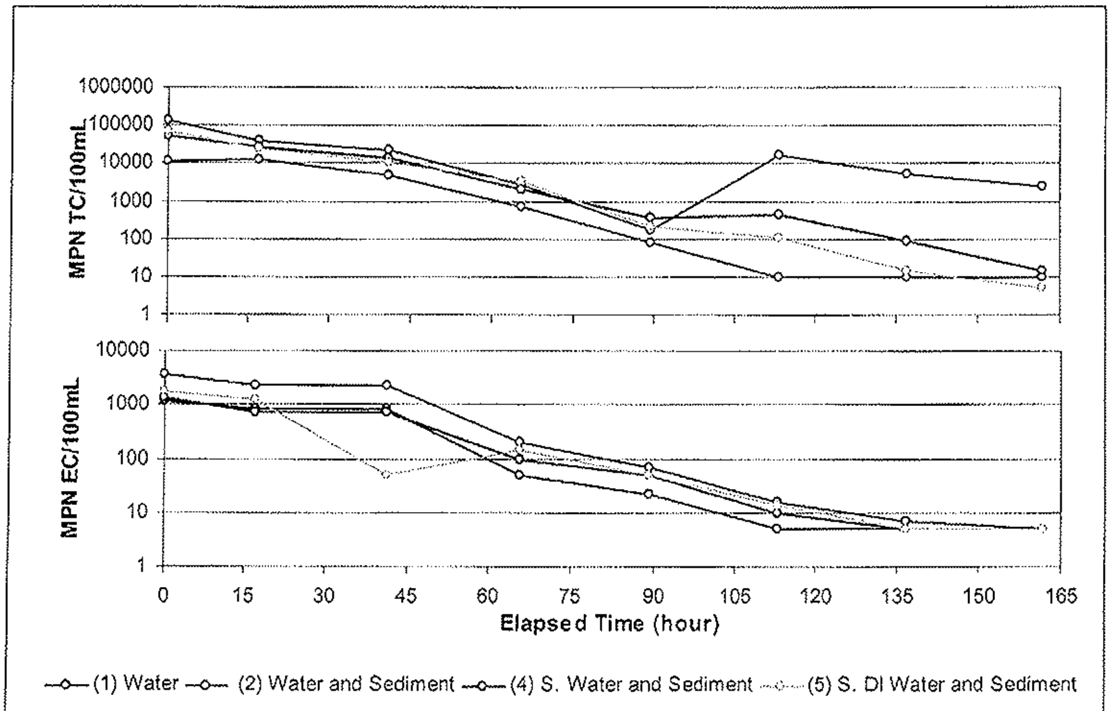


Figure 6-6. Concentrations of total coliforms and *E. coli* versus elapsed time during Study 3 (January 7, 2009).

Although the total coliform concentrations in Figure 6-6 (Study 3) seem to have increased in two Microcosms (2 and 4) around hour 115, this time is when the dilutions changed to accommodate a smaller bacteria concentration. When dilutions switched from 1 part sample water and 99 parts sterilized deionized water to 10 parts microcosm water and 90 parts sterilized deionized water, the accuracy of the reading may have increased, or human error occurred in filling the pipets.

This is the only study which yielded similar results for the total coliforms and *E. coli* in all microcosms. Possibilities for this could be the nutrient interactions. This study yielded high dissolved oxygen, nitrate, and DOC concentrations. These nutrients together may be most conducive to bacterial survival.

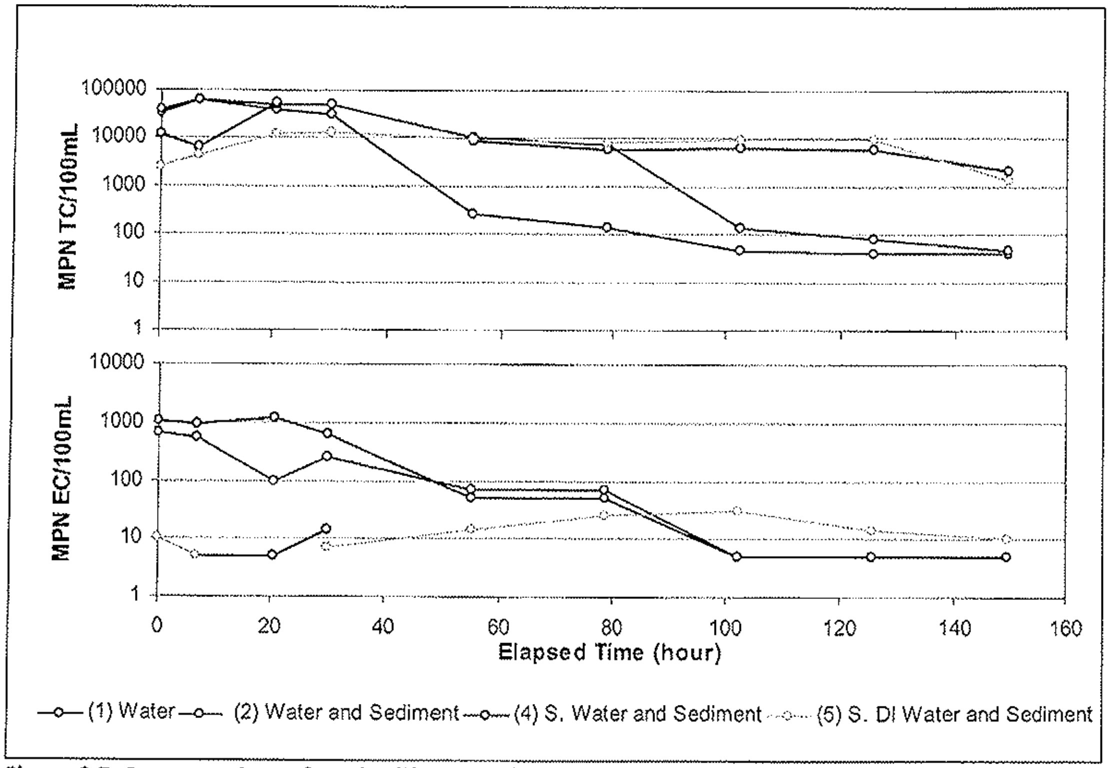


Figure 6-7. Concentrations of total coliforms and *E. coli* versus elapsed time during Study 4 (April 10, 2009).

Microcosms 4 and 5 are missing data points for the *E. coli* concentrations in Figure 6-7 (Study 4) because the dilutions made for those rounds were too large to give plausible measurements, i.e. the concentration was less than 100 MPN/100mL, so estimating 50 MPN/100mL for a microcosm that previously had less than 3.5 times that concentration is not appropriate. This is another study where Microcosm 1 and 2's total coliform concentration decrease faster than Microcosm 4 and 5's. Microcosm 1 and 2's last concentrations differ from Microcosm 4 and 5's by an order of magnitude. Microcosm 1 and 2's *E. coli* concentrations follow the same basic decrease while Microcosm 4's *E. coli* concentration stays practically the same. Microcosm 5's *E. coli* concentration shows a steady increase, and then starts to decrease towards the end.
The following are graphs of the natural log of the concentrations of total coliforms and *E. coli* versus elapsed time.

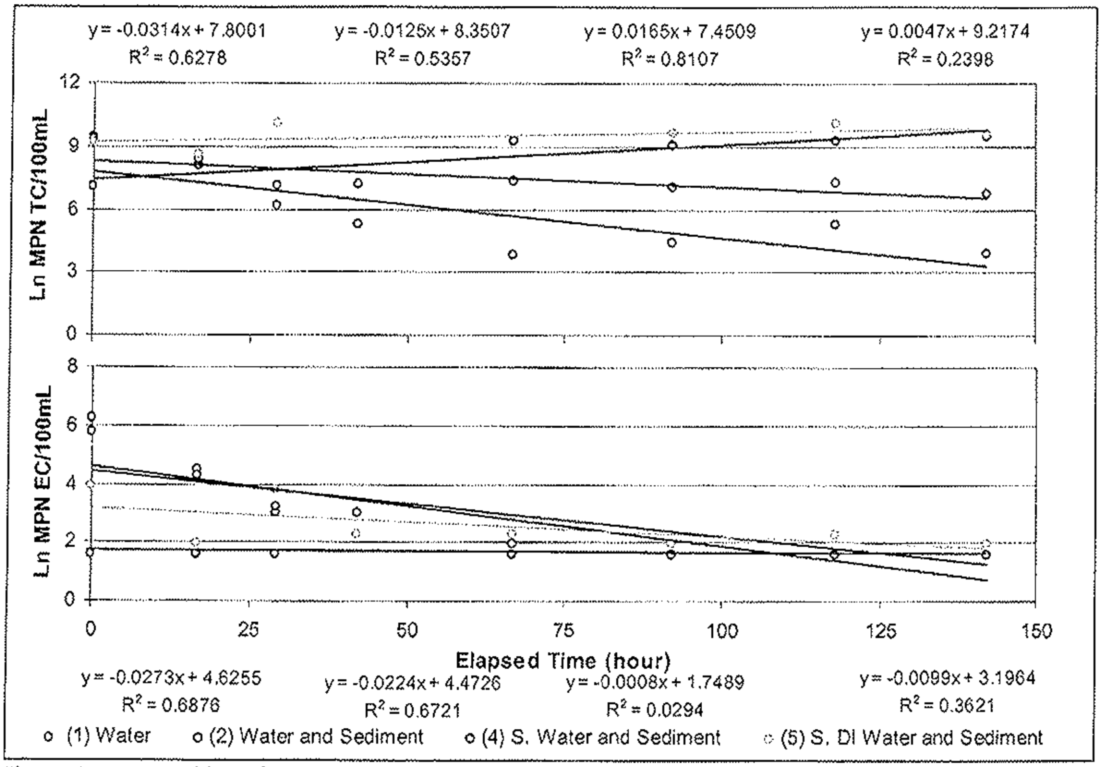


Figure 6-8. Natural log of the concentrations of total coliforms and *E. coli* versus elapsed time during Study 1 (July 11, 2008).

A first–order rate constant quantitatively expresses the decay that can be expected per unit time. The equation to integrate for a first-order model is

$$\frac{dc}{dt} = -kc$$

where k has units of t^{-1}. If $c = c_0$ at $t = 0$, then this equation can be integrated by separation of variables to yield

$$\ln c - \ln c_o = -kt$$

Taking the exponential of both sides gives

$$c = c_o e^{-kt}$$

Study 1 (Figure 6-8) resulted in total coliform rate constants of k_W= 0.031 hr^{-1}, k_{ws}= 0.012 hr^{-1}, k_{sws}= 0.016 hr^{-1}, and k_{sdws}= 0.005 hr^{-1} with R^2 values of 0.63, 0.54, 0.81 and 0.24 respectively, located in the top row of Figure 6-8. Study 1 resulted in *E. coli* decay rate constants of k_W= 0.027 hr^{-1}, k_{ws}= 0.022 hr^{-1}, k_{sws}= 0.001 hr^{-1}, and k_{sdws}= 0.010 hr^{-1} with R^2 values of 0.69, 0.67, 0.03 and 0.36 respectively, located in the bottom row of Figure 6-8.

In this study, the *E. coli* decay rate constant for Microcosm 4 was the lowest for all the studies. This is due to the concentration essentially not changing throughout the study.

Similar plots were carried out for Studies 2 through 4, as described below.

Study 2 resulted in a total coliform rate constant of k_W= 0.044 hr^{-1} with an R^2 value of 0.71. Study 2 resulted in *E. coli* rate constants of k_W= 0.001 hr^{-1}, k_{ws}= 0.008 hr^{-1}, k_{sws}= 0.008 hr^{-1}, and k_{sdws}= 0.002 hr^{-1} with R^2 values of 0.17, 0.18, 0.29, and 0.01 respectively. In this study, the *E. coli* decay rate constant for Microcosm 1 was the lowest for all the studies. This is another case where the concentration essentially did not change throughout the study.

Study 3 resulted in total coliform rate constants of k_W= 0.054 hr^{-1}, k_{ws}= 0.021 hr^{-1}, k_{sws}= 0.049 hr^{-1}, and k_{sdws}= 0.061 hr^{-1} with R^2 values of 0.93, 0.34, 0.97 and 0.98 respectively. Study 3 resulted in *E. coli* rate constants of k_W= 0.040 hr^{-1}, k_{ws}= 0.046 hr^{-1}, k_{sws}= 0.039 hr^{-1}, and k_{sdws}= 0.037 hr^{-1} with R^2 values of 0.90, 0.96, 0.96, and 0.89 respectively.

Study 4 resulted in total coliform rate constants of k_w= 0.058 hr^{-1}, k_{ws}= 0.054 hr^{-1}, k_{sws}= 0.011 hr^{-1}, and k_{sdws}= 0.003 hr^{-1} with R^2 values of 0.86, 0.91, 0.46 and 0.04 respectively. Study 4 resulted in *E. coli* rate constants of k_W= 0.043 hr^{-1}, k_{ws}= 0.035 hr^{-1}, k_{sws}= 0.003 hr^{-1}, and k_{sdws}= 0.006 hr^{-1} with R^2 values of 0.92, 0.90, 0.22, and 0.26 respectively.

Decay rate constants for total coliforms ranged between 0.03 hr^{-1} and 0.058 hr^{-1} for Microcosm 1, 0.012 hr^{-1} and 0.054 hr^{-1} for Microcosm 2, 0.011 hr^{-1} and 0.049 hr^{-1} for the Microcosm 4, and 0.003 hr^{-1} and 0.061 hr^{-1} for Microcosm 5.

Decay rate constants for *E. coli* ranged between 0.001 hr^{-1} and 0.043 hr^{-1} for Microcosm 1, 0.008 hr^{-1} and 0.046 hr^{-1} for Microcosm 2, 0.001 hr^{-1} and 0.039 hr^{-1} for Microcosm 4, and 0.002 hr^{-1} and 0.039 hr^{-1} for Microcosm 5.

6.4 Special Case: Microcosm 3 – Sterilized Sediment and Water

Microcosm 3 was to be used to demonstrate how bacteria would behave in water affected by nutrients suspending from sterilized sediment. To set up Microcosm 3, the sediment was autoclaved at 121°C for 1 hour and then added to the flask which was filled with water. Microcosm 3 was then monitored with the others. However, the results were very different. Bacteria concentrations increased dramatically then showed signs of decay towards the end of the studies.

DOC was measured in the water of all microcosms at the end of the studies. Microcosm 3 always had the highest DOC concentration at the end of the studies, and in studies 1 and 4, it was the only microcosm that had a higher final DOC concentration.

Table 6-1. Initial and final DOC concentrations for the four studies.1

ID	Date Sampled	DOC in water (mg/L)
TCR	7/11/08	2.95
Mic 3	7/18/08	6.57
TCR	8/19/08	NM
Mic 3	8/26/08	9.06
TCR	1/7/09	7.64
Mic 3	1/14/09	20.9
TCR	4/10/09	6.16
Mic 3	4/16/09	12.9

Because bacteria concentrations increased, decay rate constants were not calculated for this microcosm. However, there is a significant finding here that autoclaving sediment may release organic carbon to the water, possibly contributing to bacterial growth. After autoclaving the sediment, the DOC concentrations increased. This is based on each Microcosm 3 having a higher DOC value at the end of the studies.

It was observed that nutrient levels also increased in Microcosm 3, evident from the water sample inventory summary located in the appendix. However, nutrient concentrations also increased in the other microcosms. It is inconclusive whether the DOC or nutrient concentrations or both are responsible for the bacterial growth in Microcosm 3.

7 Conclusions

7.1 Part A: Creek Studies

The mean kinetic rate constant (k) for total coliform, which includes all of the total coliform k values from both experiments is 0.0346 hr^{-1}; the k for *E. coli* is .0308 hr^{-1}. These values are very similar, only differing by nearly four thousandths of a decimal.

The k values for September and October are similar with the largest difference between the *E. coli* for DAV2 (0.0149 hr^{-1}).

7.2 Part B: Lower Lake Studies

7.2.1 Water Quality

The maximum allowable concentration of *E. coli* for recreational waters is 235 MPN/100 mL for any single water sample (EPA 1986). The lowest initial water concentration measured during

[1] Although the DOC sample was not measured in the second study, the final DOC concentration in Microcosm 3 was approximately 27% greater than the second highest DOC concentration.

the study was 355 MPN/100 mL. According to Stevens Institute of Technology (2009) the nitrate and phosphate concentrations exhibited excellent water quality, and the dissolved oxygen concentrations exhibited fair to good water quality.

7.2.2 Bacteria Decay Rates

Microcosm 1's total coliform concentration decreased the fastest in all studies, excluding study 3's Microcosm 5. Microcosm 1's *E. coli* concentration decreased the fastest in studies 1 and 4. Microcosm 2's total coliform and *E. coli* concentration decreased second fastest to Microcosm 1 in Studies 1 and 4.

Comparing Microcosms 1 and 2, a lower decay rate is expected from Microcosm 2, since it contained sediment, which contained nutrients. Microcosm 2, did, however, have a higher *E. coli* decay rate constant in Study 2 and 3 than Microcosm 1.

The highest concentrations of dissolved oxygen, nitrate, and DOC were recorded during studies 3 and 4. The bacteria concentrations were also the largest during these studies. It should be noted that the initial TOC concentration in the sediment was below the detection limit ($<$ 0.05%) during these studies. It is assumed that the nutrients in the water were responsible for the high concentrations of both bacteria groups.

During Study 3, Microcosm 5's total coliforms decreased the fastest, which was followed by Microcosm 1. This is the only study where Microcosm 1's total coliforms did not have the highest decay rate. This study is also the only one in which Microcosm 2's total coliform concentration decreased the slowest. These findings may be due to the high initial DOC concentration.

During Study 4 the total coliforms in Microcosm 1 decreased the fastest, followed Microcosm 2. Microcosm 5's *E. coli* concentration slightly increases while Microcosm 4's *E. coli* concentration nearly remains unchanged. This study is the only one in which *E. coli* showed growth (5). Based on the cumulative microcosm graphs, Microcosm 1 yielded the highest decay rates for total coliforms (0.047/hr) and *E. coli* (0.037/hr). Microcosm 2 yielded the highest decay rate for *E. coli* (0.032/hr) while Microcosm 4 had the third highest decay rate for *E. coli* (0.024/hr). Microcosm 4 is the only microcosm that shared the values (0.024/hr) for total coliform and *E. coli* decay rate constants, suggesting that the microcosm environment had similar impacts on both bacteria populations. These graphs show that bacterial decay will occur faster when not influenced by sediment.

7.2.3 Special Case: Microcosm 3 – Sterilized Sediment and Lake Water

Results of Microcosm 3 suggested that autoclaving sediment may release DOC to the water, possibly contributing to bacterial growth. After autoclaving the sediment, the DOC concentrations increased. This is based on each Microcosm 3 having a higher DOC value at the end of the studies. Bacteria concentrations were always higher in Microcosm 3, excluding the last two rounds of the first study in which microcosms four and five had higher concentrations of total coliforms.

7.2.4 Implications for Water Quality Modeling

Distinct decay rates for bacteria were found specific to each microcosm. These rates can be taken into account when modeling for water quality. Whereas today's models consider only published decay rates of bacteria in water, this research aims to introduce decay rates, or at least a methodology to generate decay rates, that are influenced by sediment and nutrients.

7.2.5 Implications for Water Quality Management

It was found that in the sampling location for this study, *E. coli* concentrations were always above the maximum concentration allowed by USEPA (see section 4.1). The likely cause of the high concentrations is the consistent presence of dozens of birds in the vicinity. While the sampling collection site is not a swimming beach, it is within 600 m of a swimming beach. If the swimming beach were affected by bacteria contributed by the birds, one management option would be to establish an alternate bird habitat farther from the lake.

7.3 Recommendations for Further Analysis and Future Research

Recommendations for further research include conducting an investigation with a sufficient number of repetitions to enable a comprehensive statistical analysis of results. Perhaps multiple studies during the different seasons would suit research needs better by indicating when bacteria concentrations are at their highest and what water quality indicators are a primary influence on bacteria concentrations.

Although the sediment-water ratio showed no correlation with bacteria concentration, further studies could incorporate microcosms of similar composition but with different sediment-water ratios. For example, comparing a microcosm of water alone with 1) a microcosm consisting initially of a two-to-one sediment-water ratio and 2) a microcosm consisting initially of a four-to-one sediment-water ratio could possibly show an effect that sediment has on the bacteria concentration in the water.

For further studies a sediment particle size analysis should be conducted on the initial sediment sample from each study. This could possibly show an association of sediment particle size with bacteria concentration.

Watershed Assessment and Education

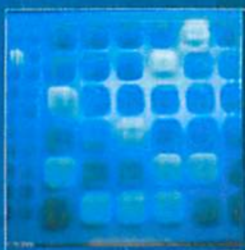
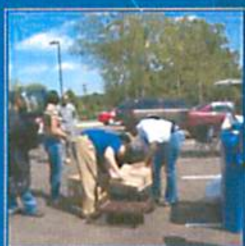
Basic Information

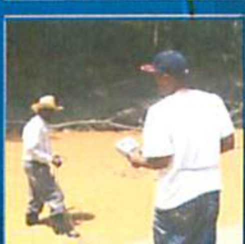
Title:	Watershed Assessment and Education
Project Number:	2008MS82B
Start Date:	7/1/2008
End Date:	6/30/2010
Funding Source:	104B
Congressional District:	02
Research Category:	Water Quality
Focus Category:	Water Quality, Education, Surface Water
Descriptors:	None
Principal Investigators:	Maifan Silitonga

Publications

1. Quarterly reports submitted 2008-2010 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Silitonga, M. and A. Johnson, "Watershed Assessment and Education" presentation made at the 2009 Mississippi Water Resources Conference, August 5-7, 2009, Tunica, MS, in Conference Program, p. 6, http://www.wrri.msstate.edu/conference.asp.
3. Silitonga, M., Watershed Assessment and Education, oral presentation at 2009 Mississippi Water Resources Conference, August 5-7, 2009, Tunica, MS, Conference Proceedings, p. 152, http://www.wrri.msstate.edu/pdf/2009_wrri_proceedings.pdf.
4. Silitonga, M., A. Johnson, 2010, Watershed Assessment and Education, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 28 pgs.



Alcorn State University

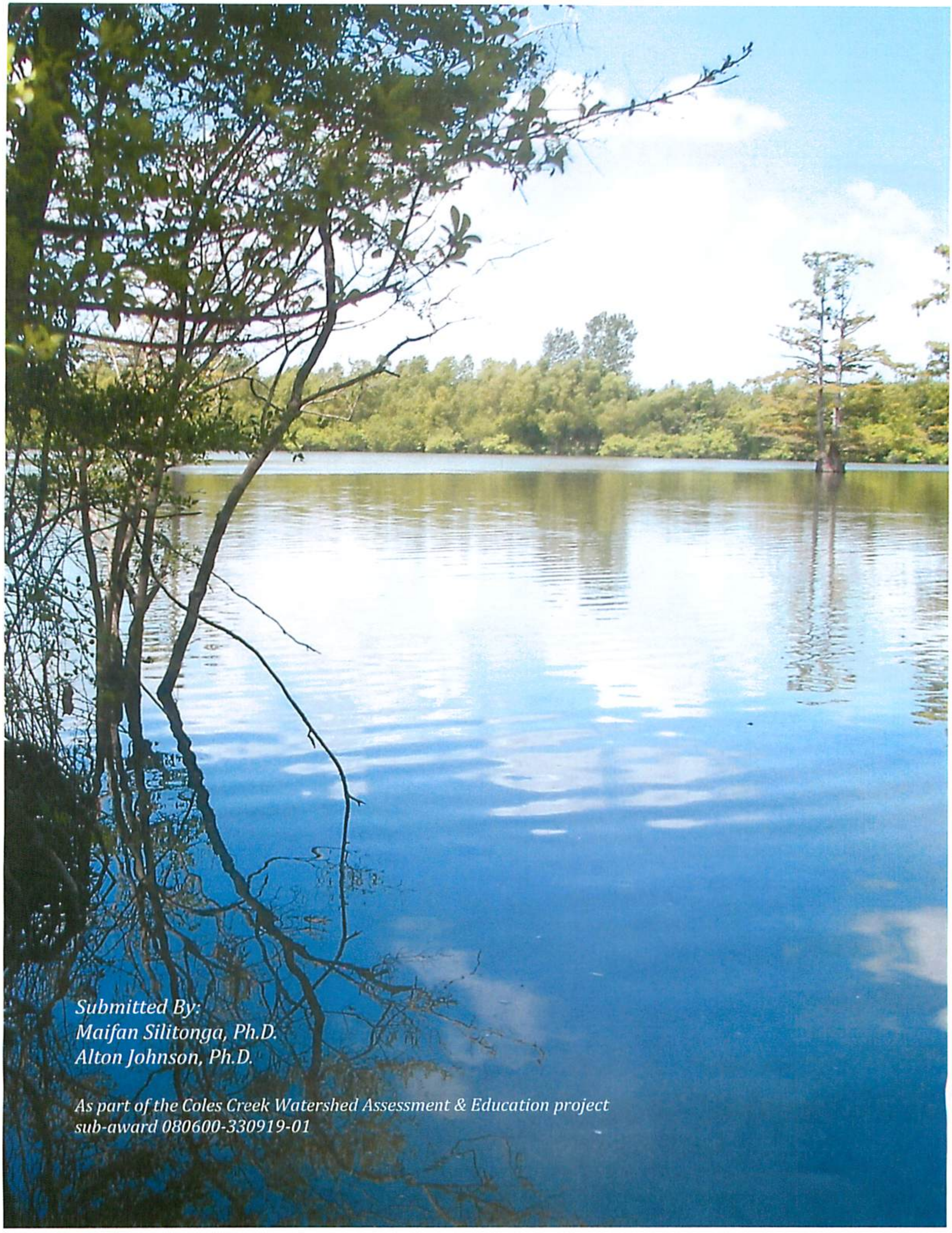
Mississippi River Research Center

Center for Ecology & Natural Resources

Technical Report

Submitted to:
US Geological Survey
Mississippi Water Resources Research Institute

COLES CREEK watershed Assessment & Education



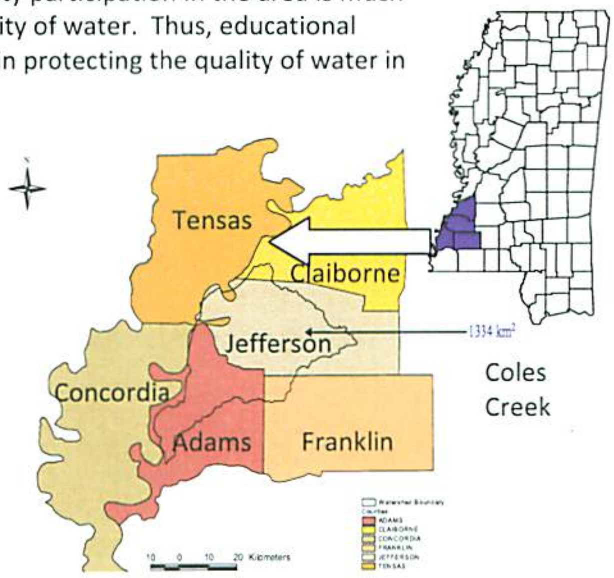
Submitted By:
Maifan Silitonga, Ph.D.
Alton Johnson, Ph.D.

As part of the Coles Creek Watershed Assessment & Education project
sub-award 080600-330919-01

Table of Contents

Project Summary

The Coles Creek Watershed, located in the southwestern quadrant of the state of Mississippi, is listed under the US EPA impaired water section 303(d). Degradation of the ponds/lakes and streams/creeks in this watershed is caused mostly by biological impairment, followed by nutrients, organic enrichment or Low Dissolved Oxygen, sediment/siltation, pesticides, and pathogens (US EPA, 2007). These impairments cause the degradation of water quality thus causing euthrophication or algal bloom that can lead to fish kills and can also adversely affect human health. The causes of algal blooms have not been studied; therefore, data is needed to evaluate the quality of water and soil in the surrounding areas of the watershed. The data obtained will be used to analyze and determine the situation and find effective methods to solve the problem. Community participation in the area is much needed to improve, maintain, and restore the quality of water. Thus, educational materials are necessary to engage the community in protecting the quality of water in this area.



Each water body is unique depending upon its geological characteristics such as natural landscape features and human activities related different land uses and land-management practices. In the Coles Creek Watershed, several identified water bodies have been heavily impaired.

Poor water quality can harm fish, wildlife, and their habitats. Many things are known to cause poor water quality including: sedimentation, runoff, erosion, dissolved oxygen, pH, temperature, decayed organic materials, pesticides, and toxic and hazardous substances. Therefore, identifying the cause of degradation and finding the best management practice(s) (BMPs) as well as protection strategies have to be developed for each lake, pond, or river, individually.

The purpose of the study is to investigate, assess, and find solutions to improve the quality of surface water bodies that can be adopted and implemented in the watershed.

The objectives are to:

1) Analyze the quality of water in water bodies (streams, creeks, and ponds)
2) Analyze soil samples in the surrounding areas
3) Identify the cause of degradation
4) Find and select the best management practice(s) to restore the ponds' conditions
5) Develop educational materials for the community

Approach and Methods

Students will collect water and soil samples from these ponds to be analyzed for selected chemical, physical and biological parameters. The analysis of the results will help find and determine the best alternative management practices to be adopted and implemented in the community. Based on the results and findings, educational materials will be developed and disseminated to the communities. This effort will help increase the community awareness of their environment and encourage them to adopt and implement BMPs on their land which will lead to promoting environmental health and its sustainability, thereby, having good water quality to support the economic development in the area. In addition, extension agencies will also be engaged in this study to assist communities and be the voice of the university as well as to continue assistance after the funding period.

The associated specific tasks to reach the goals include:

1) Spatially geo-reference water bodies
    a. Students will locate surface water bodies in the Coles Creek watershed and geo-reference their positions.
    b. The locations of these water bodies will be displayed using Geographic Information System (GIS) for visualization and further analysis.
2) Analyze the physico-chemistry of waters.
    a. Soil and water samples from each of the geo-referenced waters will be collected and analyzed for nutrients and pathogens that cause to eutrophication.
3) Spatially identify and inventory landuse/land covers impacting water quality.
    a. Using GIS/ArcView capability, to identify landuse/landcover's surrounding these water bodies.
    b. The landuse/landcover's in the areas will be assessed and evaluated to determine the correlation of impacts.
4) Determine factors that influence contaminant transport in the environment and the spatial correlation of water quality.
    a. Soil samples will be analyzed.
    b. Geologic settings and the soil hydraulic properties as well as the spatial structures will be studied to understand soil-water dynamics of the surface and sub-surface interactions affecting contaminant movement.
5) Identify restoration strategies to improve the quality of water.
    a. Restoration strategies will be formed based on the linkage between impairment and pollutant loading to surface water bodies, which is an essential component of watershed assessment.
    b. Numerical modeling will be used to establish linkages or correlations between impairment and pollutant loading due to the lack of monitoring data.
6) Develop a scientifically- credible watershed restoration plan.
    a. Identify site-related Best Management Practices (BMPs).
7) Encourage implementation of identified best management practices and watershed restoration plan.
    a. Disseminate outreach and educational materials to introduce the concept of pollution prevention to the community.
    b. Conduct workshops or participate in workshops to disseminate information to the public.

8) Develop monitoring database to support the State's database for monitoring the quality of water in the Coles Creek Watershed.
    a. Data collected will be tabulated in a database and analyzed.
    b. Data will be available for future analyses and comparisons to observe changes of water quality over time.

Results

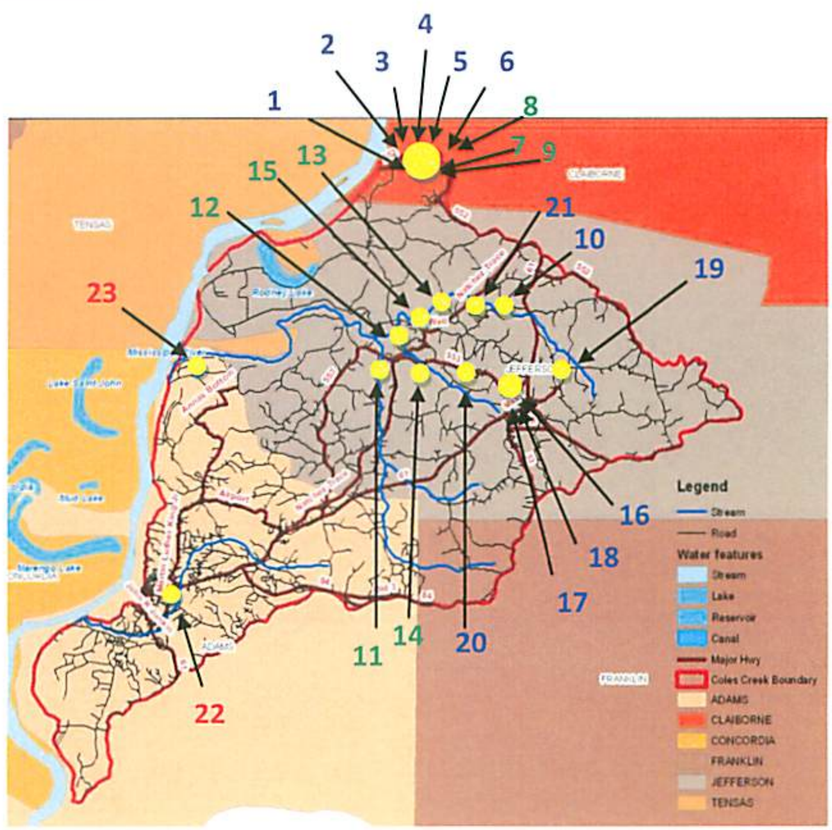
Some of the tasks identified above were able to be completed within the funding period. Data collected and presented below, with the consideration of several circumstances, such as inevitable extreme weather conditions, dried creeks, muddy soil, snakes in the water, etc. along with other technical difficulties and the lack of manpower. Continuous educational programs and analysis of the watershed will continue beyond the duration of the project.

Geo-Reference of Sampling Locations

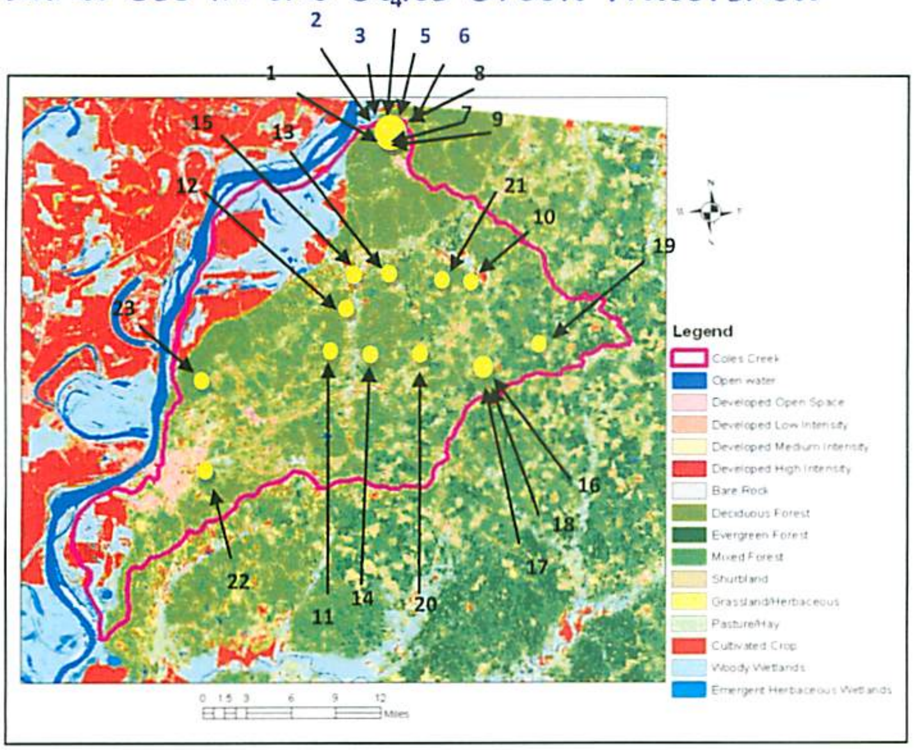
Faculty and students observed potential sampling locations using references from previous sampling locations, maps, USGS Sampling Locations, Google Earth map, ESRI – ArcView map and ground survey. The geo-referenced sites are listed in Table 1.

Table 1. Geo-referenced Sampling Locations

ID	Location
1	ASU Model Farm (p)
2	ASU C-factor (p)
3	ASU Burrus Hall (p)
4	ASU house (p)
5	ASU Gym (p)
6	ASU park (p)
7	Hwy 61S PG 1 (p)
8	Hwy 61S PG 2 (p)
9	Hwy 61S PG 3 (p)
10	Old Hwy 61 S Jeff (p)
11	Fairchild Creek
12	South Fork Coles Creek
13	North Fork Coles Creek
14	Mud Island Creek
15	Dowd Creek
16	Hwy 61 S Jeff 1 (p)
17	Hwy 61 S Jeff 2 (p)
18	Hwy 61 S Jeff 3 (p)
19	Coonbox Rd.
20	Hwy 553 Jeff bridge (p)
21	Coles Creek
22	St. Catherine Creek
23	Anna's Bottom



Land Use in the Coles Creek Watershed



The land-use in the Coles Creek Watershed is predominantly forested areas (mostly deciduous forest, with some mixed and evergreen forest). The watershed also consists of cropland with sparsely located high density areas (rural areas). The landuse information is extracted from the National Land Cover Dataset (NLCD).

Water Quality Physical, Chemical, and Biological Properties

Water quality in the Coles Creek Watershed were collected and analyzed from 23 sampling locations. Samples from these locations were monitored monthly for the duration of 13 months. Collections of samples in several locations (ASU C-factor, Old Highway 61S, and HWY 553 Jeff Bridge) were discontinued because the water bodies have dried up. Sampling and monitoring water from Fair Child Creek and South Coles Creek were started in August 2009. These locations were difficult to reach and were discovered after the initial sampling began. Samples were collected from ponds, lakes, creeks, and streams, with (p) denoting water collected from a pond.

Parameters tested include: pH, temperature, turbidity, total dissolved solid (TDS), dissolved oxygen (DO), nitrate (NO3), total coliform, E. coli, and chlorophyll. Temperature, pH, turbidity, total dissolved solids, dissolved oxygen, nitrate, and chlorophyll were analyzed using YSI Sonde 6000s water monitoring instrument. Total coliform and E. coli were sampled and analyzed using IDEXX Quanti-tray method.

Temperature

The most common physical assessment and basic properties of water quality is the measurement of temperature. Temperature impacts both the chemical and biological characteristics of surface water; the higher the water temperature, the greater the biological activity.

In a warmwater stream temperatures should not exceed 31.7 °C or 89 °F and cold water streams should not exceed 20 °C or 68 °F. Temperature can affect other parameters and is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. Temperature on water chemistry affects the impact on oxygen where warm water holds less oxygen than cool water. Also, some compounds are more toxic to aquatic life at higher temperatures. Furthermore, many aquatic organisms are sensitive to high temperatures because solubility of oxygen is lower, thus limiting oxygen supply in the water.

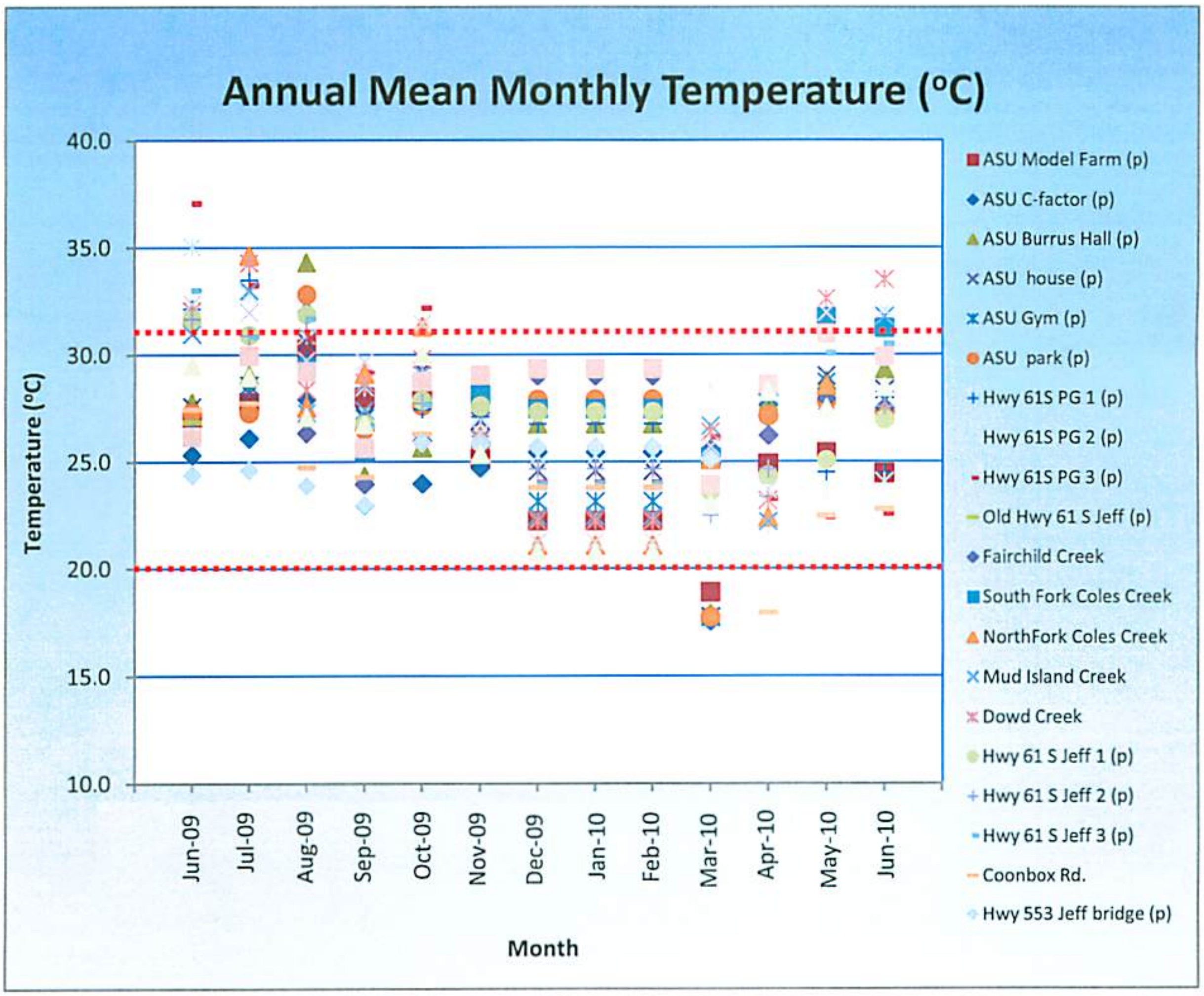


Figure 1. Annual Mean Monthly Temperature (°C)

The mean monthly temperatures in sampling locations vary with June 09 having the highest average temperature and the lowest occurred in November 2009. The water temperatures in most sampling locations fall within the range between 20 and 32°C with higher temperatures in some locations during the summer period and lower temperature in March 2010.

In June, July and August of 2009, the temperature in several water bodies increased to above 32°C. This increase may be caused by several factors. In urban areas, runoff that flows over hot asphalt and concrete pavement before entering a lake will be artificially heated and could cause lake warming, although in most cases this impact is too small to be measured. Consequently, direct, measurable thermal pollution is not common. In running waters, particularly small urban streams, elevated temperatures from road and parking lot runoff can be a serious problem for populations of cool or cold-water fish already stressed from the other contaminants in urban runoff. During summer, temperatures may approach their upper tolerance limit. Higher temperatures also decrease the maximum amount of oxygen that can be dissolved in the water, leading to oxygen stress if the water is receiving high loads of organic matter. The problem of low dissolved oxygen levels is magnified by the fact that the metabolic rates of aquatic plants increase as water temperature rises, thus increasing their biochemical oxygen demand. Low dissolved oxygen levels leave aquatic organisms in a weakened physical state and more susceptible to disease, parasites, and other pollutants. Water temperature fluctuations in streams may be further worsened by cutting down trees which provide shade and by absorbing more heat from sunlight due to increased water turbidity.

Further assessment is needed to observe the fluctuations of temperature and to evaluate the correlations between the water body and the surrounding land-use.

pH

pH determines the acid and base characteristics of water. A pH of 7.0 is neutral; values below 7 are acidic and values above 7 are alkaline. Excessively high or low pH levels are often associated with nutrient deficiencies, metal toxicities, or other problems for aquatic life. High pH makes ammonia more toxic. During algal blooms, photosynthesis increases the water pH, especially in stagnant or slow-moving water.

A pH range of 6.0 to 9.0 provide protection for the life of freshwater fish and bottom dwelling invertebrates. In a lake or pond, the water's pH is affected by its age and the chemicals discharged by communities and industries. Most lakes are basic (alkaline) when they are first formed and become more acidic with time due to the build-up of organic materials. As organic substances decay, carbon dioxide (CO_2) forms, thus lowering the pH.

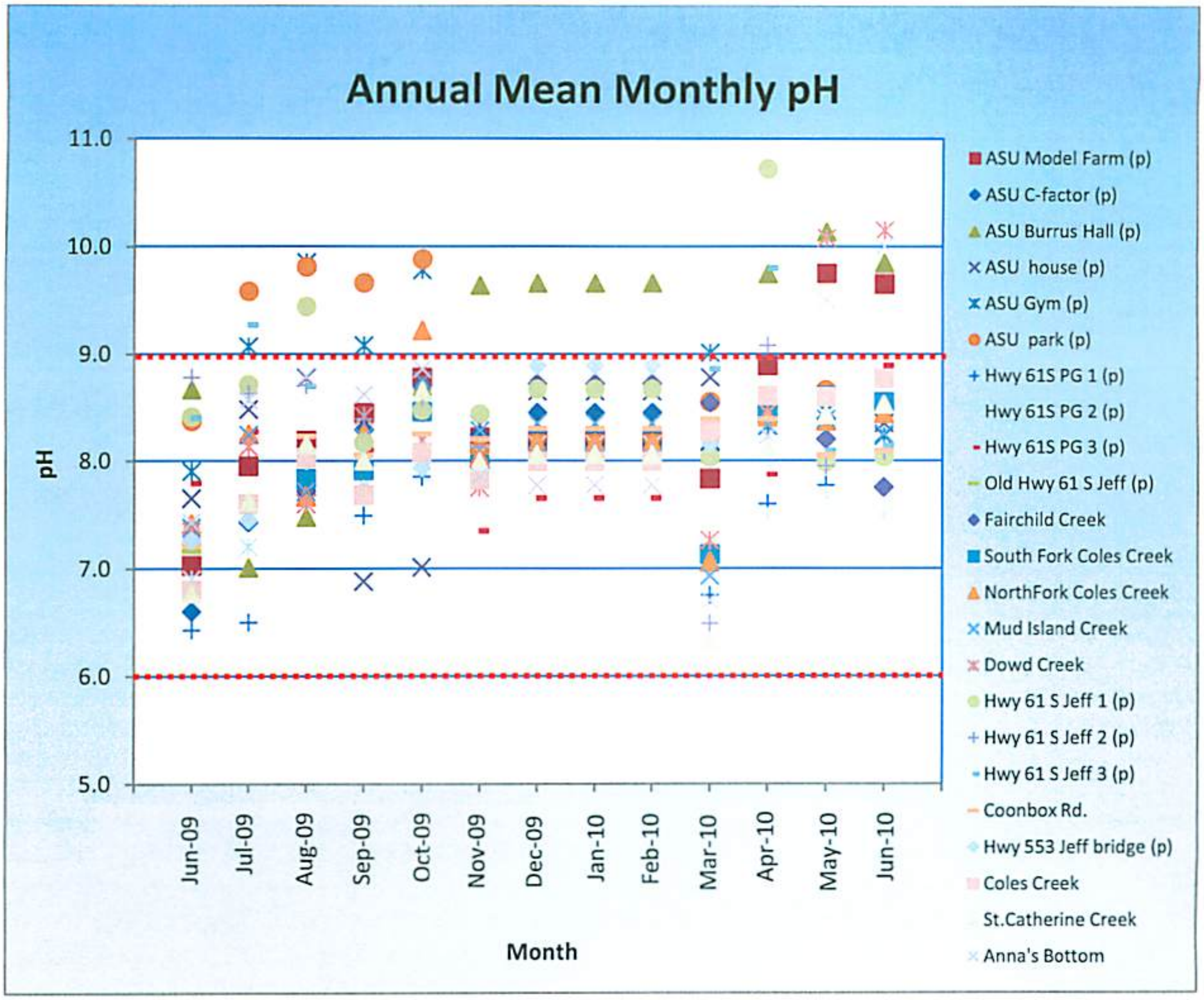


Figure 2. Annual Mean Monthly pH

Most of the pH values in these sampling locations fall within the range of 6 to 9, with 10.8 as the highest and 6.2 as the lowest. Most of the data falls within the neutral to basic ph range. Some pH are higher that may be contributed from liming of cropland, geological setting, runoff from the roads, etc. Further investigation is needed to determine the cause.

Turbidity

Turbidity is the measurement of water clarity. Suspended sediments, such as particles of clay, soil and silt, frequently enter the water from disturbed sites and affect water quality. Suspended sediments can contain pollutants such as phosphorus, pesticides, or heavy metals. Suspended particles cut down on the depth of light penetration through the water, hence they increase the turbidity -- or "murkiness" or "cloudiness" -- of the water. High turbidity affects the type of vegetation that grows in water. The turbidity values are expressed in nephelometric turbidity units (NTUs).

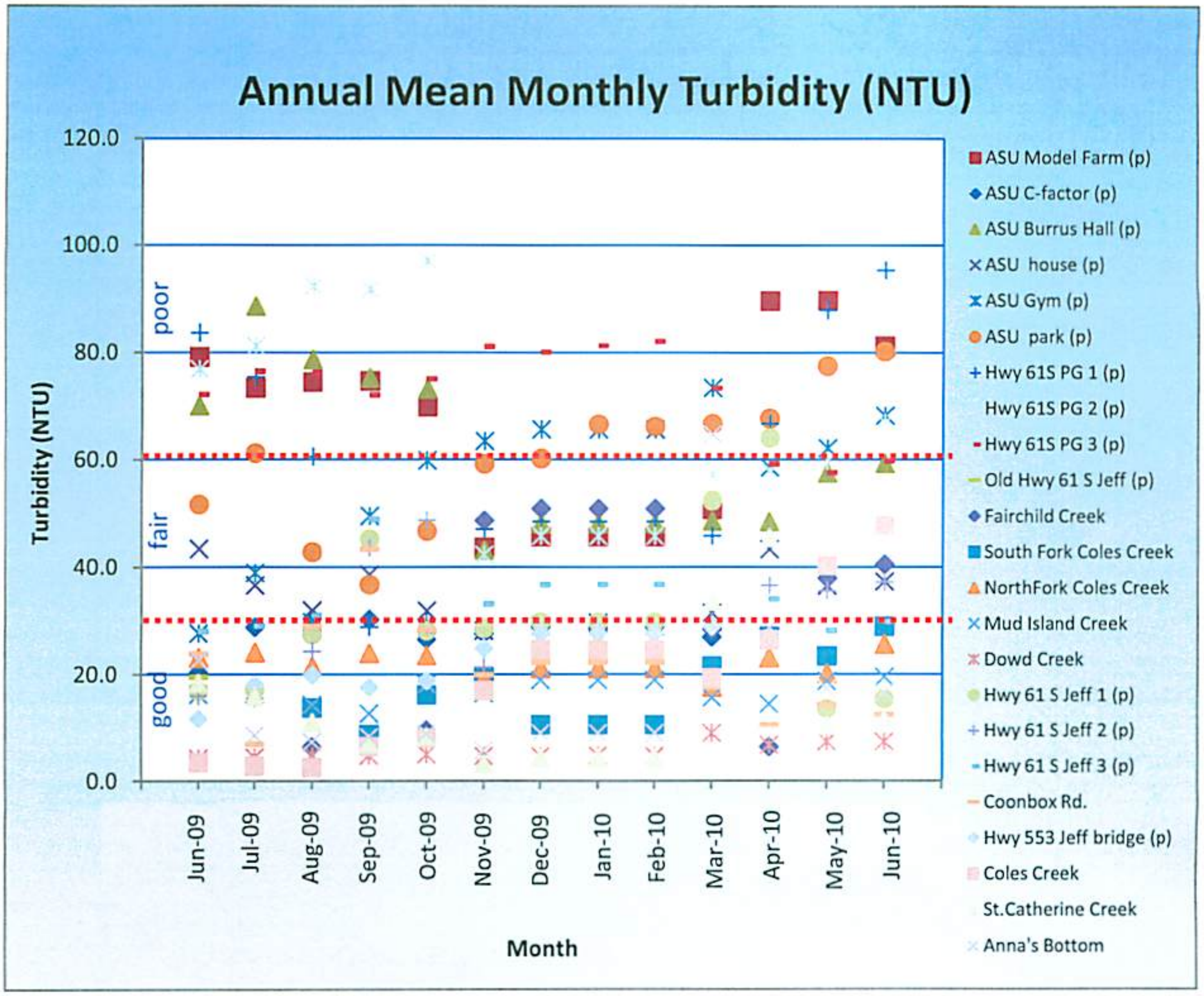


Figure 3. Annual Mean Monthly Turbidity (NTU)

The turbidity of water in the watershed varies from good to poor throughout the year with stream water having better turbidity than pond waters. This could be affected by the types of soil, management practice, or the type of land-use. Studies to understand the spatial and temporal variability will require further investigations that include climate, land-use/land cover, and soil types.

Turbidity levels are much higher in water from surface water sources (e.g. streams, rivers, and lakes) than from groundwater sources. Some surface water sources exhibit high turbidity levels during periods of high precipitation and subsequent runoff from plowing in cultivated farmlands (e.g. spring runoff). River rating scale designates 0-30 NTU as good (low murkiness), 30-

60 as fair (moderate murkiness), and over 60 as poor (high murkiness). For drinking water, turbidity must not exceed 5 NTU.

Total Dissolved Solids

Total dissolved solids is the total amount of dissolved ions in the water. The total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. This amount is determined by Electrical conductivity (EC). Electrical conductivity is an indicator data that can detect contaminants, determine concentration of solutions, and determine the purity of water. Conductivity meters give readings in micro Siemens per cm (μS/cm) while TDS is measured in parts per million (ppm) or mg/L.

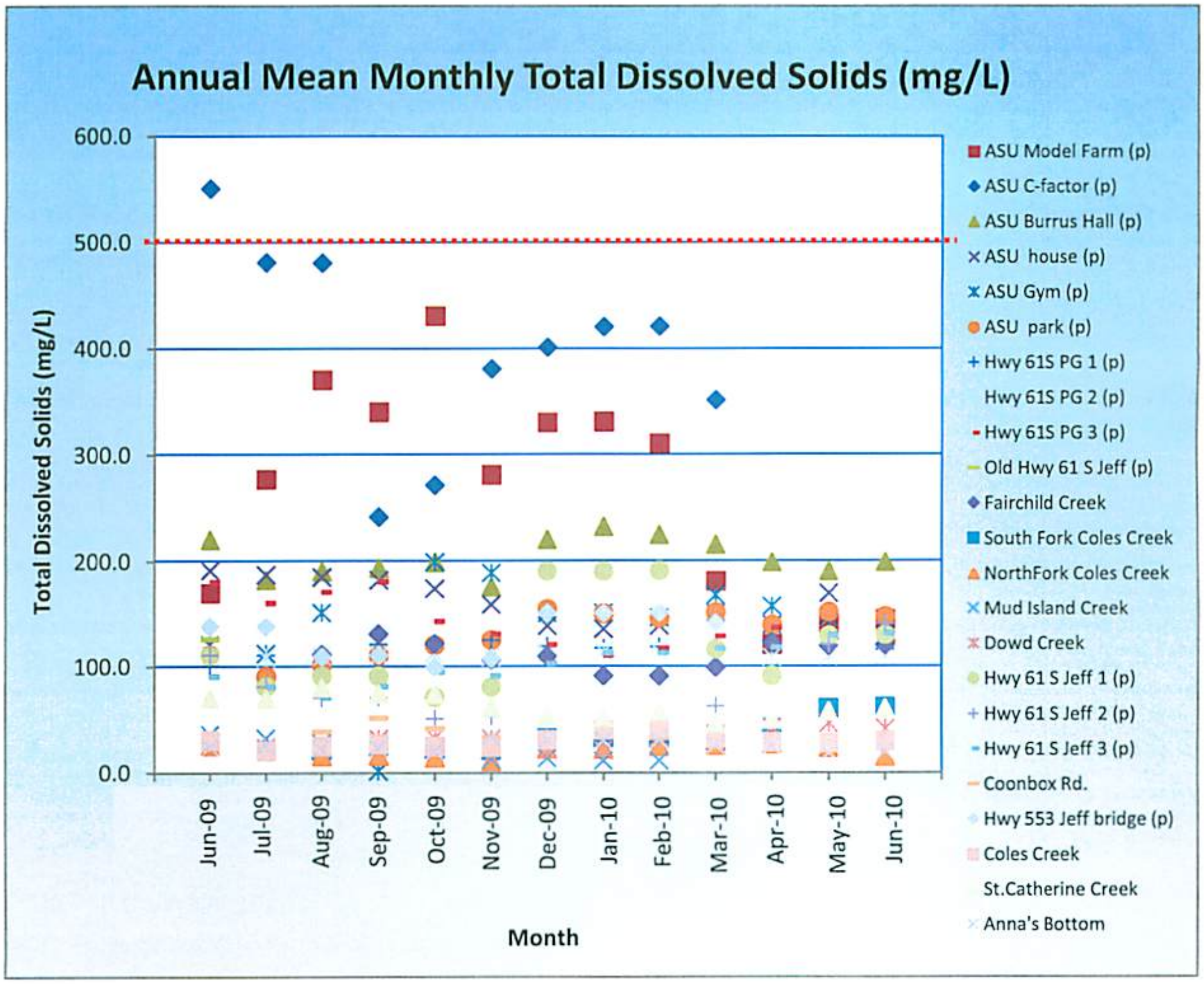


Figure 4. Annual Mean Monthly Total Dissolved Solids (mg/L)

Most fresh drinking water will have less than 100 µS/cm conductivity. Some slightly salty drainage water will have around 1800 µS/cm conductivity. Very brackish water could be about 27000 µS/cm and seawater has conductivity of around 54000 µS/cm. Water with TDS <1500 mg/L is considered fresh water, 1500 to 5000 mg/L as brackish water, and saline water >5000 mg/L. The amount of TDS ranges from 100-20,000 mg/L in rivers and may be higher in groundwater. Seawater may contain 35,00 mg/L of TDS. Lakes and streams may have a TDS reading of 50-250 mg/L.

An elevated total dissolved solids (TDS) concentration does not mean the water poses a potential health hazard. For drinking water, TDS is regulated as a secondary standard because it is more of an aesthetic or causes nuisance problems, associated with staining, taste or precipitation.

With respect to trace metals, an elevated total dissolved solids may suggest that toxic metals may be present at an elevated level. On the other hand, water with a very low TDS conce ntration may be corrosive that may leak toxic metals such as: copper and lead from the household plumbing. Toxic or trace metals could be present at levels that may pose a health risk.

Most samples collected from these sites have TDS below 500 mg/L, indicating that aesthetic issues are not a concern in the area during the observation period. One sample from a location has a TDS above 500 mg/L. The probable cause for high TDS reading is unknown and further study will not be possible because the site has dried up.

Dissolved Oxygen

Oxygen is a necessary element to all forms of life and adequate dissolved oxygen is necessary for good water quality. Natural stream purification processes require ade quate oxygen levels in order to provide for aerobic life forms.

Dissolved oxygen (DO) analysis measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. DO in a stream may vary from 0 mg/l to 18 mg/l. The DO level in good fishing waters generally averages about 9.0 parts per million (ppm) and 4-5 ppm of DO is the minimum amount that will support a large, diverse fish population. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills.

Most water in the watershed have relatively acceptable dissolved oxygen level throughout the year. Although a few water bodies have low level of DO, none of them are low enough to cause fishkill.

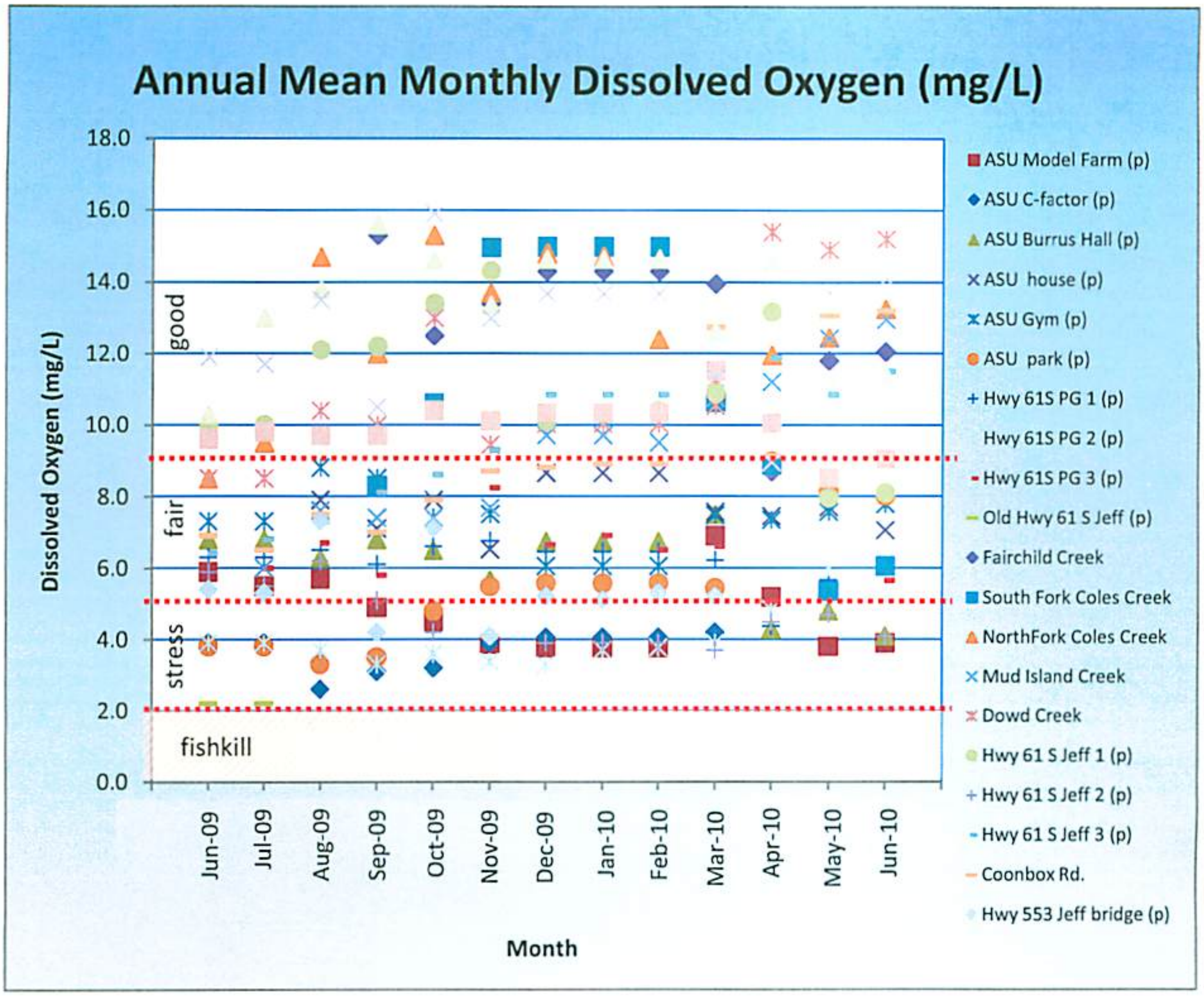


Figure 5. Annual Mean Monthly Dissolved Oxygen (mg/L)

Nitrate

Nitrate (NO_3^-) forms in water when bacteria use dissolved oxygen to oxidize ammonium. Nitrate is mobile and may seep into streams, lakes and estuaries from ground water enriched by animal or human wastes or commercial fertilizers. High concentrations of nitrate can enhance the growth of algae and aquatic plants.

Nitrate is considered as a contaminant that may pose an adverse health effect. Therefore, nitrate is regulated as a

Primary Standard for safe drinking water that allowing the maximum contaminant level (MCL) to be 10 ppm or mg/L as nitrate-N.

Throughout the year, nitrate ($NO3-$) levels in several locations are found to be below 10 mg/L. Nitrate enters the water bodies through municipal and/or industrial wastewater, septic tanks, feed lot discharges, animal wastes (including birds and fish) and discharges from car exhausts. Many of these sample sites are located in rural and undisturbed areas. Factors that may contribute to the nitrate level in the water could be from animal wastes, vegetation decomposition, and applications from agricultural lands.

Nitrogen-containing compounds acts as nutrients in streams and rivers. Bacteria in water convert nitrites ($NO2-$) to nitrates ($NO3-$). Nitrate reactions in fresh water can cause oxygen depletion. Thus aquatic organisms depending on the supply of oxygen in the stream can be adversely affected.

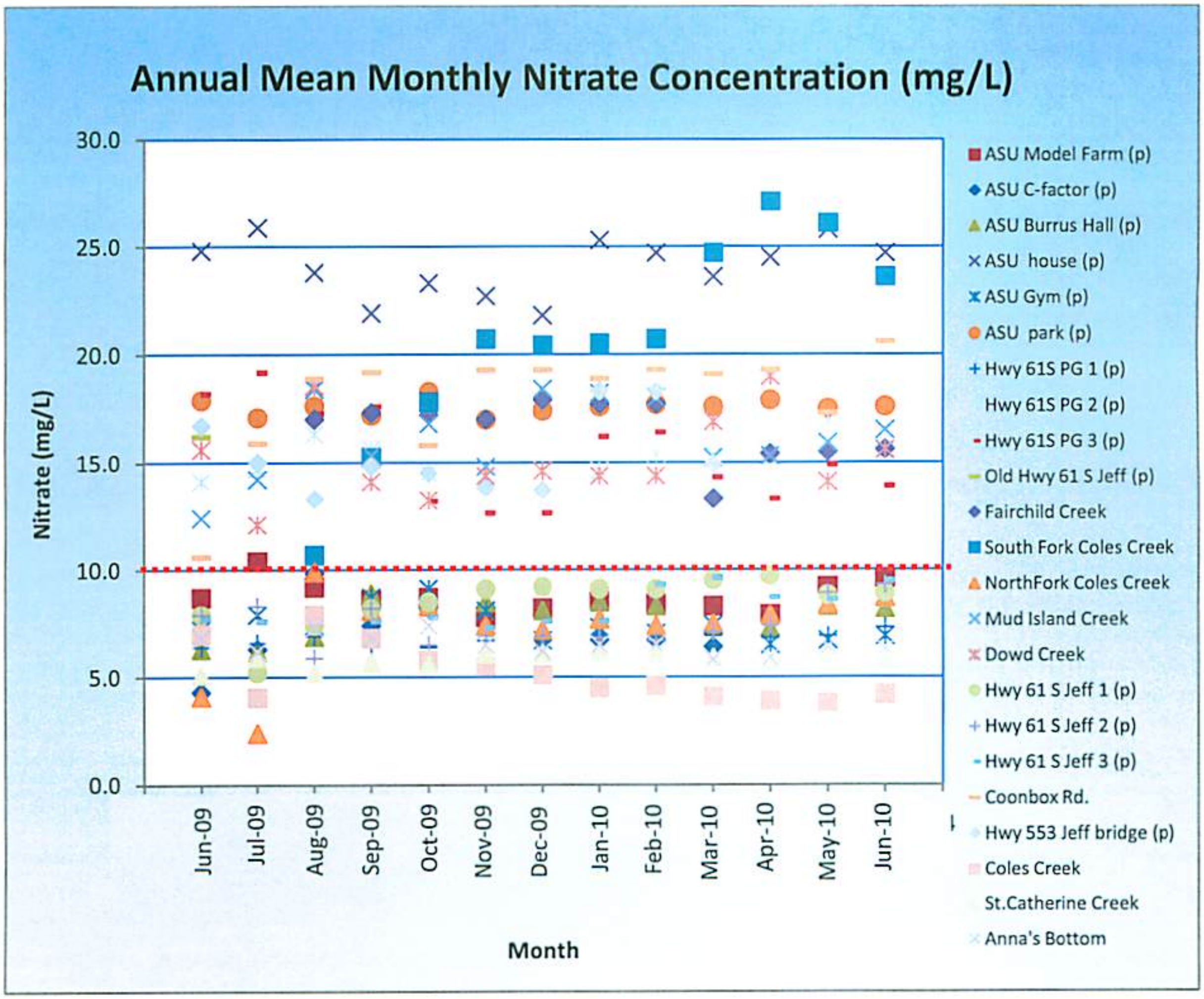


Figure 6. Annual Mean Monthly Nitrate (mg/L)

Chlorophyll

Chlorophyll in various forms is bound within living cells of photosynthetic organisms, such as phytoplankton and cyanobacteria (blue-green algae). The amount of chlorophyll found in a water sample is used as a measure of the concentration of phytoplankton. These measurements contribute to the understanding of the general biological "health" of the system, such as its trophic status or primary production.

Chlorophyll measurements can also identify algal bloom events and their effects on water quality and anticipate toxic algal blooms.

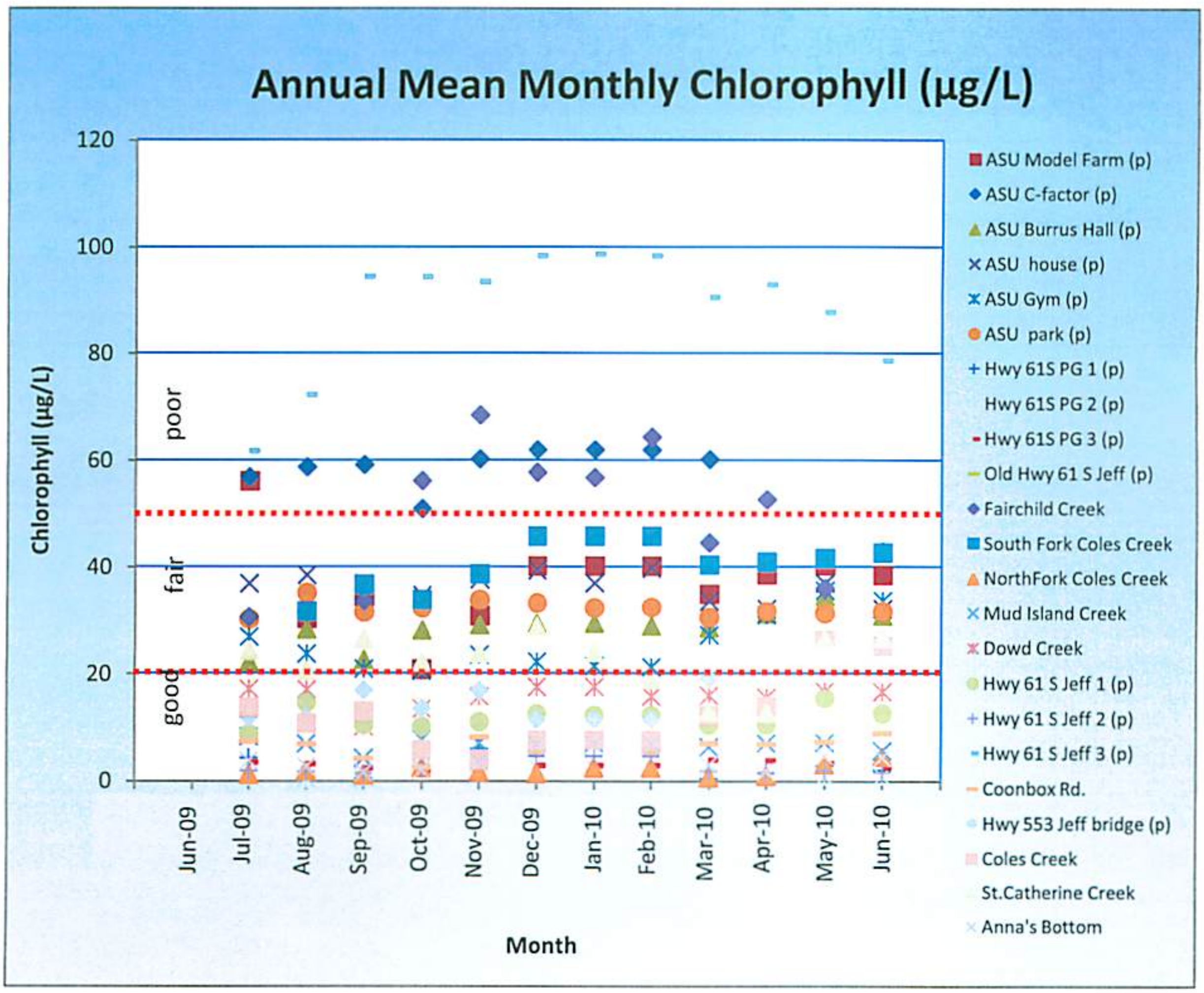
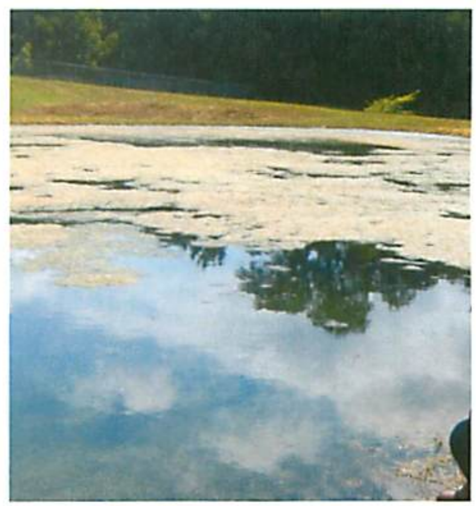


Figure 7. Annual Mean Monthly Chlorophyll (µg/L)

Chlorophyll fluoresces when irradiated with light of a particular wavelength (435-470 nm). For field measurements, in-situ fluorometers induce chlorophyll to fluoresce by shining a beam of light of the proper wavelength into the water and then measuring the higher wavelength light which is emitted. In general, the amount of chlorophyll in a collected water sample is used as a measure of the concentration of suspended phytoplankton.

Advances in fluorescence technology have lead to the capability of semi-quantitative measurement of chlorophyll in water, without extraction or chemical treatment, thereby allowing in situ (in-place) measurements.

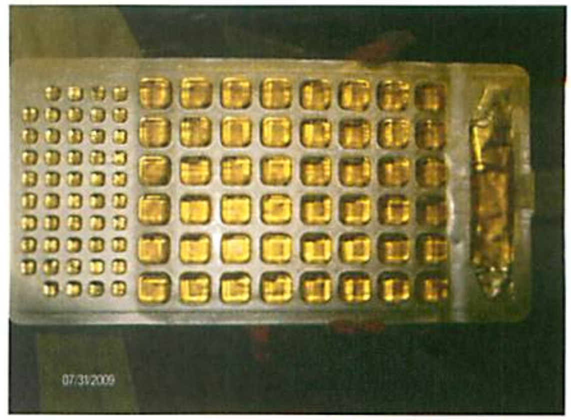
From the results, it can be seen that most of the chlorophyll levels in the watershed are found to be relatively good to fair. These measurements can be used as an indicator of phytoplankton or algal biomass in the water column. Further study will be needed to correlate the chlorophyll concentration and the column or depth of the sampling.



Chlorophyll in the water are not harmful to human health, but may cause adverse environmental impact, such as reduced water clarity, low dissolved oxygen due to decaying phytoplankton, food supply imbalances, proliferation of species that may potentially be harmful to aquatic or human life, and or causes aesthetic conditions that are unsuitable for designated uses. Increased nutrient availability, for example from human activity (e.g. agricultural runoff, soil erosion, discharges of sewage and aquaculture waste), usually leads to a rise in chlorophyll concentrations in the waters because of the increased phytoplankton biomass.

Total Coliform

Total Coliform Test-theoretically indicates the presence of all coliform group bacteria, both vegetative and fecal in origin. Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in the intestines of man and warm- and cold-blooded animals. They aid in the digestion of food. Total coliform test indicates the presences of all coliform group bacteria, both vegetative and fecal origin. A specific subgroup of this collection is the fecal coliform bacteria, the most common member being Escherichia coli. These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated only with the fecal material of warm-blooded animals. 60% to 90% of total coliforms are fecal coliforms and more than 90% of fecal coliforms are usually Escherichia coli (E. coli).



The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of man or other animals. At the time this occurred, the source water may have been contaminated by pathogens or disease producing bacteria or viruses which can also exist in fecal material. Some waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis A. The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. Fecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste. Immersion in bacteria-contaminated water can result in infections of the eyes, ears, nose, and throat (Mueller *et al.*, 1987).

Bacterial contamination falls under the category of pathogens. The EPA Maximum Contaminant Level (MCL) for coliform bacteria in drinking water is zero (or no) total coliform per 100 ml of water. The recommendation for body-contact recreation is fewer than 100 colonies/100 mL; for fishing and boating, fewer than 1000 colonies/100 mL; and for a source of domestic water supply to be treated, fewer than 2000 colonies/100 mL.

The results from samples show that all of the water bodies contain total coliform that may contain pathogens. Further assessment is necessary to determine the correlation between fecal coliforms, E. coli, and the types of land-use. Furthermore, additional frequent sampling is necessary to determine the presence of the coliform. Although these water bodies are not designated for recreational use, the high concentration of coliform should be monitored.

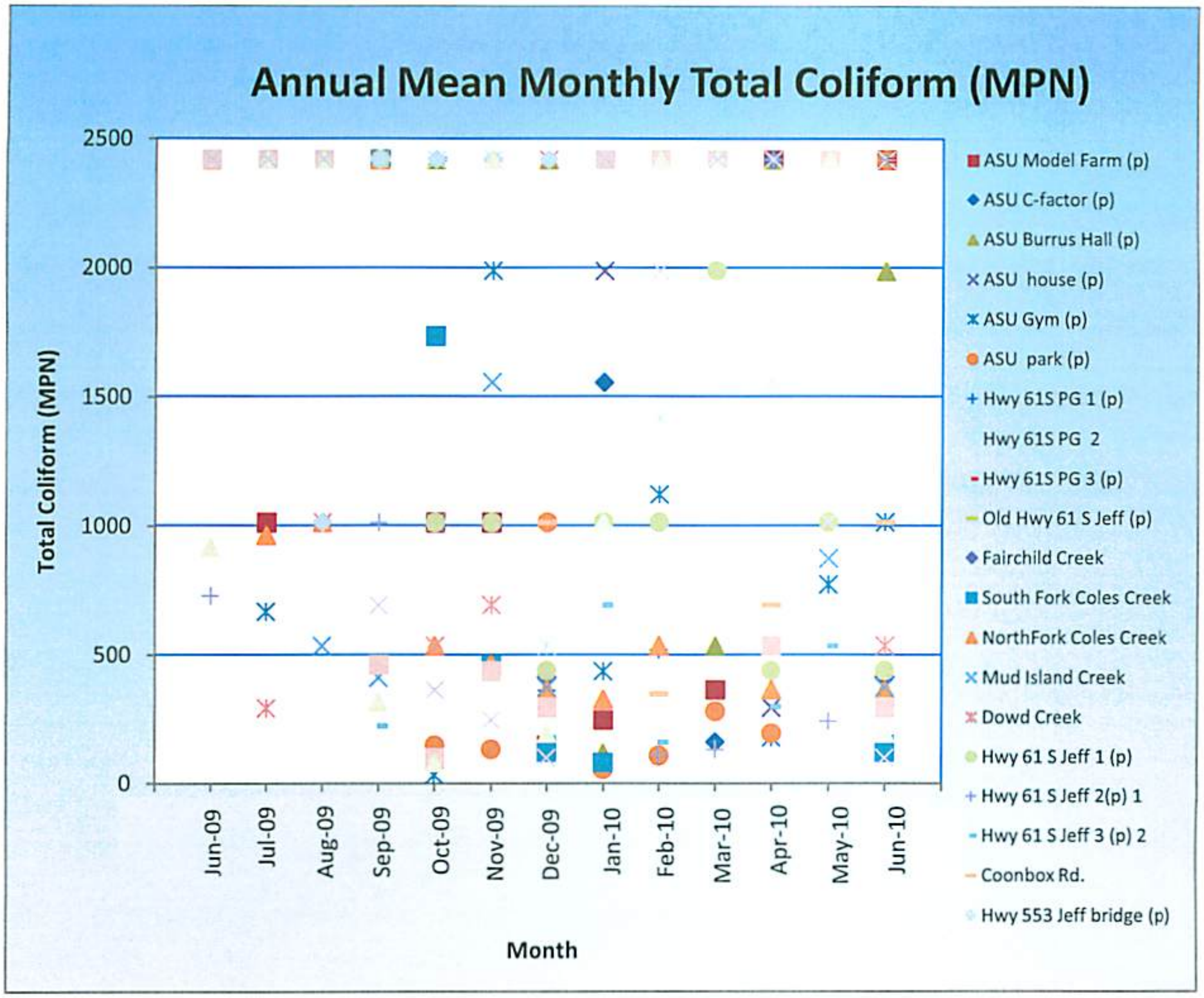


Figure 8. Annual Mean Monthly Total Coliform (MPN)

Escherichia coli

Escherichia coli is a rod-shaped bacteria that lives in the lower intestines of warm-blooded mammals. It is necessary for the proper digestion of food but its presence in surface water indicates fecal contamination. E.coli belongs to a group of bacteria (some of which are harmful) known as fecal coliform bacteria.

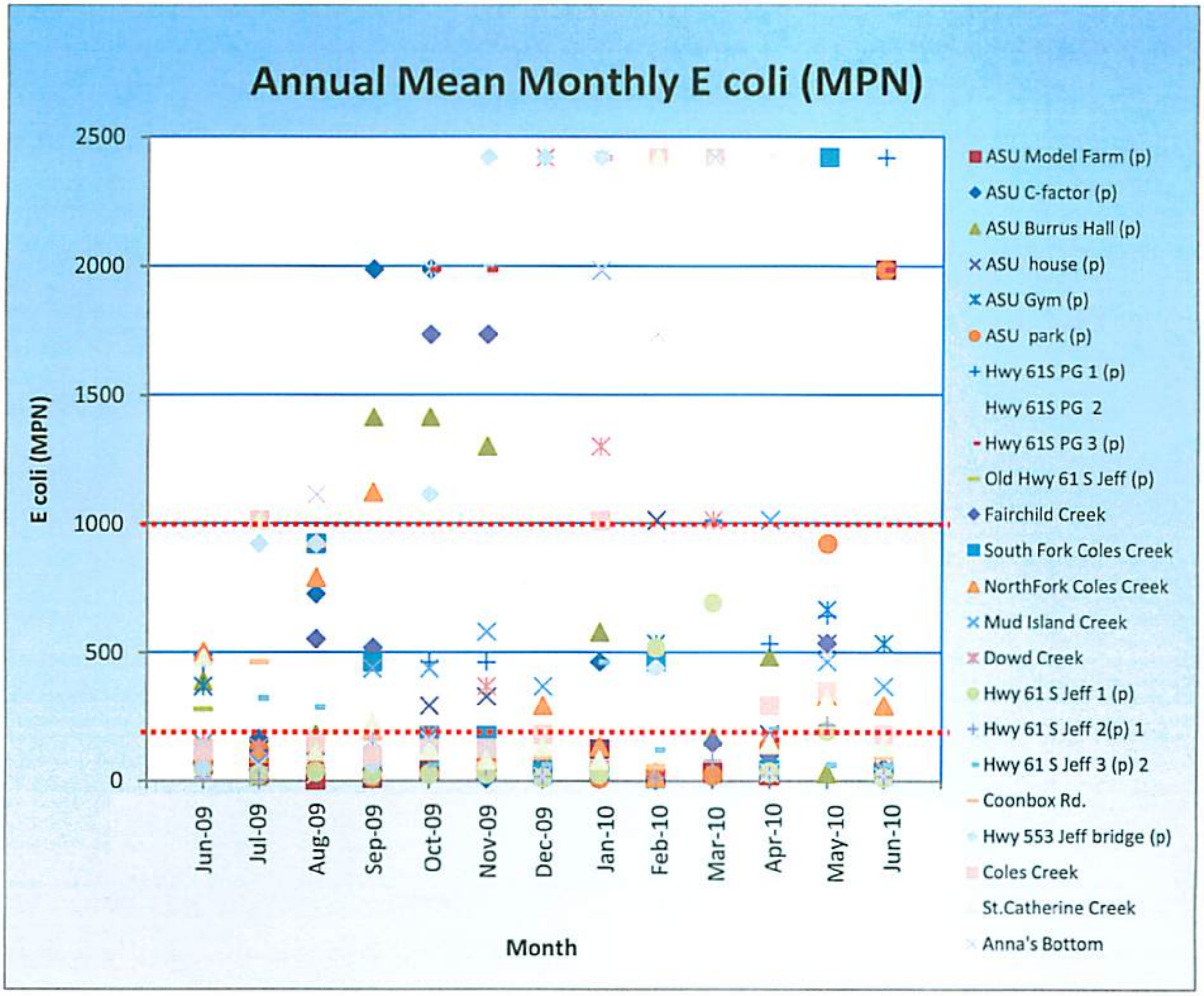


Figure 9. Annual Mean Monthly E. coli (MPN)

Certain strains of *E.coli* can be toxigenic, meaning they create a toxic by-product, causing severe bloody diarrhea and abdominal cramps that can harm humans and can be fatal to children and seniors The EPA recommended criteria for E. coli is 235 MPN/100 mL.

The recreational water guideline is less than 126 MPN/100 ml, averaged from 5 samples during a 30-day period. The single sample guideline is less than 235 MPN/100 mL. An advisory is recommended between and 235 MPN/100 mL and 1000 MPN/ 100 mL. A closure is recommended at greater than 1000 / 100 mL.

The observed data shows that while most of the water sampled have E. coli concentrations that are below and within the advisory guidelines for recreational use, many are found to be in the higher concentration limit. Further study will be needed to observe the correlations between land-use and the presence of E. coli.

Watershed Education and Stewardship

As part of the educational outreach and stewardship effort to promote preservation of water quality in the Coles Creek Watershed, several activities have been conducted as listed below. Some of workshops and activities performed were in conjunction with other events or ongoing activities to maximize our effort in reaching students and people from different communities, including limited-resource farmers and under-served communities. These outreach efforts are:

Storm Water Management Project

In June 2009, tThe Mississippi River Research Center in collaboration with the Mississippi Department of Environmental Quality (MDEQ) conducted a Stormwater Protection Educational Workshop to increase public awareness about the importance of protecting our water resources. Opening and welcoming remarks were given by Dr. Barry Bequette (Dean of School of Agriculture, Research, Extension, and Applied Sciences) and Dr. Alton Johnson (Interim Research Director), followed by educational information delivery by Mr. Johnny Biggert (MDEQ). There were approximately 55 participants; consisting of 15 faculty, staff, and students from the Departments of Agriculture and Chemistry; 22 students from the Summer Apprenticeship program; and 18 students Ag Academy program. Students learned how to preserve water resources by turning off the faucet in between brushing their teeth and not to litter as they will end up in the rivers, creeks, etc. Students from the Summer Apprenticeship program then continued with marking storm drains, a total of 102 across campus. The markings of the drains will notify others not to dump into these drains and avoid water pollution.

Non-Point Source Education Tour of the Mississippi River

On Thursday, October 1, 2009, The Mississippi River Research Center- Center for Ecology & Natural Resources in collaboration with the Mississippi Department of Environmental Quality/Non-point Source Division conducted a nonpoint source educational tour. This tour provided experience for students to cruise the majestic Mississippi River, the 3rd largest river in the world. During this event, students were exposed to non-point source pollution – pollutions from diffused or unknown sources such as agricultural practices. Students learned that the Mississippi River watershed collects water from 31 states in the U.S.

They now have a better understanding of non-point source pollution, how it can degrade the quality of the water, and how they can help protect water resources. As part of their educational experience, students also learned about the disciplines that support environmental science, a multidisciplinary approach to solve complex environmental issues. Areas covered include basic applied sciences such as biology and chemistry; natural resource economics; watershed assessment and analysis that support environmental decision making and policy development; math and physics in computational modeling; and geographic information systems. There were about 35 participants, which include students from programs in Plant & Soil Science, Agriculture Economics, Agriculture Business, Biology, Chemistry and Advanced Technology.

The trip increased the students' awareness of the importance of protecting water quality and how they can contribute by not littering, washing their cars on the road, dumping into waterways, etc. Furthermore, the tour with a boat ride offered a different experience for the majority of the students.

Earth Day Recycling Competition

The Mississippi River Research Center – Center for Ecology & Natural Resources conducted a Recycling Competition as part of the ASU Earth Day Celebration in April 2009 and April 2010. The events were organized by students of Plant & Soil Science – Environmental Science program, from the Department of Agriculture. During these events, several student organizations registered to participate, including ROTC, Agribusiness & Economics Club, SIFE, ASU Softball Team, Delta Mu Delta Business Honor Society, Zeta Chapter of Zeta Phi Beta Sorority, Alpha Kappa Mu, and Alpha Phi Alpha. Collectively, about 1700 lbs of papers, 200 lbs of aluminum cans, and 200 lbs of plastic bottles were accumulated in 2009 and increased to about 1850 lbs in 2010.

The winners of these competitions were announced during the ASU Earth Day Celebration seminar. Students and other seminar participants learned how a community can become together in the effort to preserve the environment.

Participants learned how everyone lives in a watershed. They also become aware that their daily activities can have an impact to others, not just their neighbors, but others in the Coles Creek Watershed, and ultimately outside the watershed. The recycling program is anticipated to increase awareness of more people in the community and encourage them to participate in the future or even implement recycling and preservation of the environment.

Drinking Water Quality and Human Health

During the Small Farmers Conference in March 30, 2010, the Mississippi River Research Center – Center for Ecology & Natural Resources participated in conducting an educational presentation to address non-point source pollution that can directly and indirectly affect drinking water and human health.

At this venue, approximately 60 participants of the conference attended this workshop. Some of the participants live in the Coles Creek Watershed while others live outside the watershed. However, the concept of living in a watershed was introduced to them. In addition, they also learned about the difference between tap and bottled water. Participants were provided with information about the source of their drinking water and how individual activities can directly and indirectly

affect the quality of their drinking water supply. In this workshop, participants were given samples of water to taste; ASU tap water, ASUS tap water filtered, and bottled water. After tasting the water samples, they were asked to rank their preferences. The audience was split in their preference between bottled water and filtered ASU tap water. In either situation, they were more alert about protecting their source of water.

What You Dump is What You Drink

The Department of Agriculture, School of Agriculture, Research, Extension, and Related Sciences have sponsored Summer Apprenticeship Programs that were administered by the ASU Experiment Station. The purposes of these programs are to introduce the field of Agriculture and related sciences to students and attract them to join the program. Students were assigned with different faculty of different areas. At the end of their curriculum, students were required to prepare power point presentations to be shared with other students, faculty, staff, parents, and others.

In 2009, three (3) students were assigned to the Environmental Science program. These students were engaged in projects related to water quality issues. The topic of their project was "What You Dump is What You Drink". They learned about watershed, non-point source pollution, and surface and groundwater relationship. They also identified storm water drainage throughout the area. From this experience, they have a better understanding about water cycle and how they can participate and protect their water resources. About 80 participants of students, faculty, staff, parents, and others attended during their presentation.

Going with the Flow in the Coles Creek Watershed

In 2010, two (2) high school students were assigned to the environmental science program. These students, along with undergraduate and graduate students of Alcorn were introduced to related watershed studies and were taken on a trip to tour the Coles Creek Watershed and sampling locations. During this trip, they were given assignments and training to use Global Positioning System (GPS) to locate potential sources of contaminants and sampling locations, deploy YSI Sonde water quality monitoring instrument and read the results, how to collect water sample to test for pathogens, how to identify potential sources of contaminants and tabulate the data, and test and analyze biological parameters of water quality they collected. Photos of students in the field and in the lab are shown below.

Examples of Identified Potential Sources of Contaminants in the Coles Creek Watershed

Ag Field Day

The School of Agriculture, Research, Extension, and Applied Sciences hosts an Ag Field Day annually. During this event, many small and limited-resource farmers come to visit the campus. In this venue, participants interact with scientists and learn about new and ongoing research that can be adopted by them. This year, there were about 350 participants.

Participants were asked to locate their residence to identify whether or not they live in the Coles Creek Watershed. Approximately 70 of them are from the vicinity while others come from other counties in Mississippi.

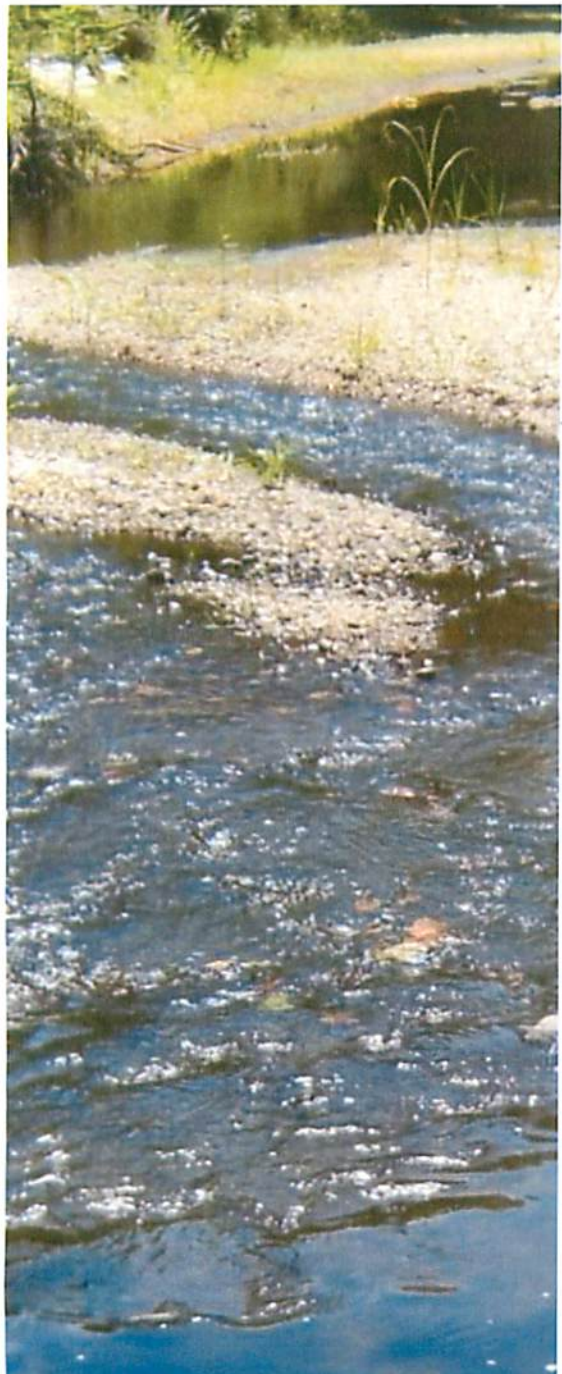
Regardless, they were exposed to the Coles Creek Watershed. They learned about the concept of watershed and how they all live in a watershed. The concept of watershed management and education in the Coles Creek can also be applied to other watersheds.

Ag High School Day

To promote the Environmental Science Program at Alcorn State University – Department of Agriculture, current ongoing research or projects are being exposed to potential students during the Ag High School Day. The Coles Creek Education Project was included in this venue.

They were informed about the sciences involved in Environmental Science and also the types of work or possible projects in this field. The graduate students of Plant & Soil Science/Environmental Science encouraged the potential students by explaining to them how water moves in the environment, including ground and surface water.

Approximately 150 high school students visited the Department of Agriculture and were exposed to the new program, a program that is not commonly found within the under-served communities.



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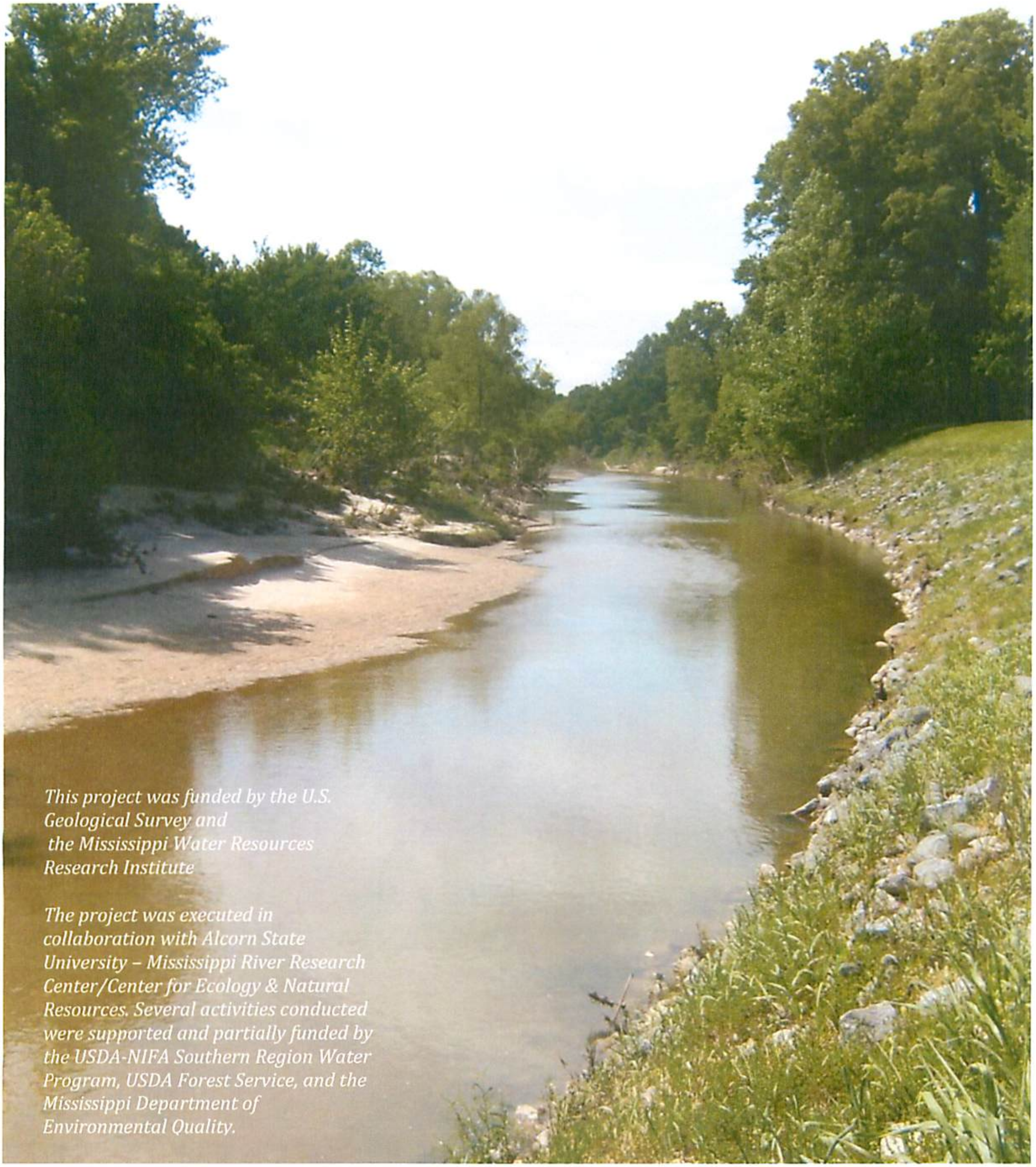

This project was funded by the U.S. Geological Survey and the Mississippi Water Resources Research Institute

The project was executed in collaboration with Alcorn State University – Mississippi River Research Center/Center for Ecology & Natural Resources. Several activities conducted were supported and partially funded by the USDA-NIFA Southern Region Water Program, USDA Forest Service, and the Mississippi Department of Environmental Quality.

Alcorn State University

USGS science for a changing world

Mississippi Water Resources Research Institute

Southern Regional Water Program

Mississippi Department of Environmental Quality

Assessing the effectiveness of measures to reduce sediment loads in surface waters using 210Pb activity in lacustrine sediments

Basic Information

Title:	Assessing the effectiveness of measures to reduce sediment loads in surface waters using 210Pb activity in lacustrine sediments
Project Number:	2009MS84B
Start Date:	3/1/2009
End Date:	1/31/2011
Funding Source:	104B
Congressional District:	1st
Research Category:	Water Quality
Focus Category:	Sediments, Water Quality, Wetlands
Descriptors:	None
Principal Investigators:	Gregg R. Davidson

Publications

1. Quarterly reports submitted 2009-2010 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Davidson, G.R., D.G. Wren, A.C. Patton and Z.A. Williams, Assessing the effectiveness of historic erosion control measures in watersheds using 210Pb in lake and wetland sediments, Baltimore, MD, March 14-16, 2010, GSA Abstracts with Programs, vol. 42, No. 1, p. 107
3. Wren, D. and G.R. Davidson, Using lake sedimentation rates to quantify the effectiveness of past erosion control in watershed, presented at 2010 Mississippi Water Resources Conference, November 3-5, 2010, Bay St. Louis, MS, online at http://www.wrri.msstate.edu/conference/abstract.asp?id=1025.
4. Davidson, G.R., 2011, Assessing the effectiveness of measures to reduce sediment loads in surface waters using 210 Pb activity in lacustrine sediments, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 20 pgs.
5. Wren, D.G. and G.R. Davidson, 2011, Using lake sedimentation rates to quantify the effective of erosion control in watersheds, Journal of Soil and Water Conservation, submitted and accepted for publication.

Assessing the effectiveness of measures to reduce sediment loads in surface waters using ^{210}Pb activity in lacustrine sediments

Final Report
March 15, 2011

Principle Investigator:
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The results of this completed project have been described in a manuscript accepted for publication (in press) in the Journal of Soil and Water Conservation.

Critical water problem addressed

Surface water quality impairment caused by erosion of agricultural fields

Abstract

The effectiveness of erosion control methods is difficult to measure, hampering the development of management practices and preventing accurate assessment of the value of erosion control structures over time. Surface erosion can vary widely over an area, particularly if gully erosion is present, and the use of sediments transported in streams for quantifying erosion is hindered by the highly variable nature of fluvial sediment loads. When a watershed drains into a lake, accumulated sediments have the potential to yield information about historic rates of sedimentation that can be used to evaluate the effectiveness of previous erosion control measures. In the present study, sediments from five natural oxbow cutoff lakes in the Mississippi River alluvial floodplain were dated using ^{210}Pb decay rates and bomb-pulse derived ^{137}Cs with the goal of relating trends in sedimentation rate to reductions in erosion due to management practices. It was found that the radioisotope dating methods were best used in concert with known dates for implementation of management practices. Changes in sedimentation rate over time frames as short as 12 years were detectable. Larger lakes showed smaller changes in sedimentation rate relative to smaller lakes.

The attached manuscript contains descriptions of the research design, objectives of the project, data collection and analysis, results and benefits, related research, and references. Additional information about the project is included below.

Technology and/or information transfer and dissemination

The primary means of technology transfer has been achieved by publication in a trade journal that is read by those interested in reducing erosion losses from agricultural fields and protecting the quality of adjacent water bodies.

Training

Three undergraduates received training in the methods employed in this study. Jacob Ferguson, Austin Patton, and Zack Williams are all students in the department of Geology & Geological Engineering. Austin Patton has since decided to stay on with the department to earn a Masters Degree, in part due to his experience working on this project.

Significant research findings

It was found that ^{210}Pb and ^{137}Cs dating methods can be used to document and quantify the effectiveness of historically applied erosion control measures. Successful application requires that lake sediments have not been significantly reworked since deposition, that erosion control measures were implemented at least 10 years earlier, and that these measures remained in effect after implementation.

Future research

Future work is under discussion considering application of the method to other lakes, and researching the possible causes of reworking of sediments in two of the sampled lakes.

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Using lake sedimentation rates to quantify the effectiveness of erosion control in watersheds

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Key words: lake—sedimentation—conservation—erosion control—^{210}Pb—^{137}Cs

ABSTRACT: The effectiveness of erosion control methods is difficult to measure, hampering the development of management practices and preventing accurate assessment of the value of erosion control structures over time. Surface erosion can vary widely over an area, particularly if gully erosion is present, and the use of sediments transported in streams for quantifying erosion is hindered by the highly variable nature of fluvial sediment loads. When a watershed drains into a lake, accumulated sediments have the potential to yield information about historic rates of sedimentation that can be used to evaluate the effectiveness of previous erosion control measures. In the present study, sediments from five natural oxbow cutoff lakes in the Mississippi River alluvial floodplain were dated using ^{210}Pb decay rates and bomb-pulse derived ^{137}Cs with the goal of relating trends in sedimentation rate to reductions in erosion due to management practices. It was found that the radioisotope dating methods were best used in concert with known dates for implementation of management practices. Changes in sedimentation rate over time frames as short as 12 years were detectable. Larger lakes showed smaller changes in sedimentation rate relative to smaller lakes.

Measuring the performance of costly watershed management practices is a problem with far-reaching ramifications. The effects of civilization and intensive agriculture cause erosion rates that are many times that of undisturbed land (Neil and Fogarty 1991; Erskine et al. 2002 and 2003; Wren et al. 2008); however, the return on funds used to correct erosion problems is largely unknown since the performance of erosion control measures is not often measured. Recent shifts towards more funding for conservation make quantification of benefits from management practices increasingly important, as reflected, for instance, by the emphasis on conservation in the 2002 Security and Rural Investment Act (Mausbach and Dedrick 2004). The need for accountability in spending tax dollars creates additional incentive for improved means to quantify decreases in erosion resulting from control measures. While the effects of conservation practices at the field scale have been extensively researched, fewer studies have focused on large-scale effects (Mausbach and Dedrick 2004). With mounting demands placed on the environment by a growing population, the need for measuring the effectiveness of erosion control projects will only grow with time (Berry et al. 2003).

It has been shown that many land owners have resisted implementation of conservation production systems at the farm level due to cost and skepticism regarding effectiveness (Swanson and Clearfield 1994). Techniques for quantifying the effect of erosion control practices may encourage reluctant landowners to implement better watershed management practices. The usefulness and life of man-made reservoirs is also impacted by sediment accumulation, creating further need for better knowledge of how well watershed management practices work (Hansen and Hellerstein 2007). The complex relationships between management practices, sediment delivery, and sediment storage have been demonstrated in the works of Trimble (e. g. Trimble 1981 and 1999), again reinforcing the need for measurement techniques to assess these relationships.

Radiometric methods, such as those utilizing ^{210}Pb, ^{137}Cs, or ^{14}C, can be used to date stored sediments, making it possible to quantify rates of sediment accumulation. Lakes that are at the downstream limit of watersheds receive and store some fraction of sediment eroded from the watershed, creating a record that can yield information on historical watershed erosion rates (Morris and Fan 1997). Such information is valuable since it allows the erosion history of watersheds to be studied, including the effects of civilization, cultivation, and management practices (e.g. Dendy and Bolton 1976; Brooks and Medioli 2003;Wren et al. 2008).

Sediments accumulated within the last century are often dated using ^{137}Cs and ^{210}Pb. The ^{137}Cs technique takes advantage of radioactive fallout resulting from the peak in atmospheric nuclear bomb testing that occurred in 1963. In many sediment cores, a clear spike in ^{137}Cs can be used to positively identify the sediment horizon laid down near 1963 (Appleby 2001; Ritchie et al. 1973). The mean sediment accumulation rate since 1963 can then be inferred from the age of the dated horizon and the thickness of sediment above it. The ^{210}Pb method yields accumulation rates from which the age of a specific horizon may be inferred from its depth. ^{210}Pb is a naturally occurring radionuclide in the ^{238}U decay series and is delivered to the atmosphere when ^{222}Rn diffuses from the subsurface and decays. Atmospheric ^{210}Pb that falls out of the atmosphere due to precipitation or dry-fall is readily adsorbed to sediment particles that are transported to lakes in runoff and deposited. This ^{210}Pb is referred to as “excess” to differentiate it from the *in situ* ^{210}Pb that is continuously produced in the subsurface. Deposited and buried ^{210}Pb decays over time, resulting in a decrease in ^{210}Pb activity with depth, with slower sediment accumulation rates reflected by larger changes in activity over a given depth interval. The method ceases to be informative at the depth where excess ^{210}Pb activity cannot be detected above the background activity (typically sediments older than 50 to 100 yr).

The goal of the present study is to relate changes in sedimentation rate, as indicated by variable slopes in ^{210}Pb profiles, to documented changes in watershed management. Cesium-137 data is also used to assess sedimentation rate. Because of difficulties in determining the exact locations and extent of management practices, the effectiveness of specific practices has not been compared. Instead, the study is focused towards determining if radioisotope techniques are sufficiently sensitive to detect recent trends in sedimentation rate and identifying a set of procedures that may be used in the future to facilitate similar measurements. The Mississippi Department of Environmental Quality was consulted regarding the location of lake watersheds where state funds have been spent and where known erosion control measures were implemented. As a result, five lakes in the Mississippi Delta region were chosen for the study: Beasley, Moon, Roundaway, Washington, and Wolf (Figure 1 and Table 1). The Mississippi Delta region is the alluvial floodplain shown in Figure 1.

Materials and Methods

Sediment cores were collected using a weighted, vibrating coring device to push 10.2 cm (4 in aluminum irrigation pipe into sediment deposits. The vibracoring method has been shown to extract relatively undisturbed samples of bottom sediments due to liquefaction of the sediment at the vibrating interface between the sample pipe and sediment (Lanesky et al. 1979; Smith 1984). Core pipes were cut to match the length of the core upon removal from the lake bed, capped, and stored at 4ºC (40ºF) until processed. The compaction ratio, assumed to be linear with depth, was determined by dividing the depth of core-pipe penetration by the length of the sediment core. Individual core increments were collected using a piston core extruder. A threaded rod pushed a piston 0.5 cm (0.2 in) per turn through a section of core pipe, enabling precise subsampling. During core extrusion and in subsequent sample preparation steps, the core increments were visually inspected for obvious variations in soil texture, such as sand lenses, and none were observed.

The proximity of cores to a local sediment source will affect results. Core locations for this study were selected far from any visible sign of locally high erosion such as failing banks, gullies, or energetic streams entering the lake.

^{210}Pb and ^{137}Cs activities were determined from powdered, bulk sediment samples which were ground, packed and sealed into 0.7 cm (0.3 in) diameter petri dishes and counted for 24 to 48 hours after at least 21 days (Allison et al. 2007). ^{137}Cs activities were determined using the 661.6 keV photopeak. Total ^{210}Pb activity was determine from the 46 keV photopeak and supported ^{210}Pb activities were determined by using averaged activities of the ^{226}Ra daughters ^{214}Pb (295 and 352 keV) and ^{214}Bi (609 keV) (Allison et al. 2007). Detector efficiencies for this geometry were calculated using a natural sediment standard (IAEA-300 Baltic Sea sediment) and detector backgrounds at each energy of interest were determined using petri blanks (Cutshall et al. 1983). Sedimentation rates based on ^{210}Pb assumed a constant rate of sediment accumulation and rate of atmospheric ^{210}Pb fallout over the period of interest. The ^{210}Pb decay rate constant of 0.0311 yr^{-1} was divided by the negative slope of the natural log of excess ^{210}Pb versus depth to arrive at sedimentation rates in cm/yr (Appleby, 2001). Uncertainty in ^{210}Pb-based estimates of sedimentation rates was calculated following the approach of Higbie (1991). The approach takes into account the range of possible slopes due to scatter in the data and provides an unbiased estimate of the uncertainty based on the available data. The repeatability of the ^{210}Pb-based method for measuring sedimentation rate was tested by comparing Wolf Lake rates derived from two separate cores separated by approximately 50 m (164 ft).

Samples were initially weighed wet, dried at 60°C (140°F) for 48 hours and weighed again. The mass of water in each increment was found by subtracting the mass of dry material from the mass of the wet material.   The water content was found by dividing the mass of water by the wet mass of the sample. Core sample thickness and depth were normalized to mean water content

(Martin and Rice 1981). This step was necessary to account for compaction in lower levels and high water content in upper levels of the cores. A given thickness of recently deposited sediments with high water content will often be compressed as additional sediment accumulation squeezes the water out of the pores. In the compressed state, the thickness of the older strata may be much lower than when the sediments were originally deposited. Normalizing by water content accounts for this difference and is particularly important when attempting to make comparisons between recent and older sedimentation rates.

Assuming minimal disturbance of sediment after deposition, the depth corresponding to the dates when erosion control measures were implemented can be found using an iterative process. The following procedure also assumes that only one time period contained major changes in management practice during the span of time covered by the sediment core. Starting with an arbitrary breakpoint at the depth of the second sample, independent sedimentation rates based on ^{210}Pb slopes were calculated for all samples above and below the trial breakpoint. The sedimentation rate for samples above the breakpoint multiplied by the years since watershed practices were changed yields a thickness of sediment that should have accumulated in that time, which can be compared with the actual thickness of sediment above the breakpoint. The same set of calculations was made again, setting the breakpoint at the third sample depth and repeating the process until the breakpoint was at the second to last sample depth. The breakpoint that yields a calculated thickness of sediment closest to the actual thickness above the sampled depth should represent sediments deposited at the time when changes in watershed management were implemented. This method assumes that management practices rather than a climate shift, flooding, or other natural process were responsible for the shift in the sedimentation rate.

The range of sedimentation rates indicated by ^{137}Cs was calculated using the depth of the points just above and below the peak activity. The actual ^{137}Cs peak could be slightly above or below the highest measured value, so the data points above and below the ^{137}Cs peak were used to provide boundaries that resulted in a range of possible average sedimentation rates. The depths of these points divided by the years that have passed since 1963 yielded a range of possible average sedimentation rates. These values proved useful for checking the plausibility of rates determined by ^{210}Pb. For comparison with ^{137}Cs-determined rates, a weighted mean rate was determined for ^{210}Pb rates from 1963 to the year of change in watershed management, and from the year of change to the time of core collection

The watershed areas for all of the lakes except for Roundaway were obtained from sources such as reports by the Mississippi Department of Environmental Quality. The watershed area for Roundaway was estimated using available topographic data. The watersheds in the study all have exceptionally flat terrain; therefore, the resolution of available topographic maps is often too low to accurately determine watershed boundaries without physically surveying large areas of land. Topographic data were used to find an approximate elevation change across the land over a distance extending roughly 1 km (0.6 mi) north and south of the edges of each lake. Longer transects reported for some lakes in the Study Area section are because the lakes themselves are larger. In all the lakes in the study, as is true over much of the Mississippi Delta, the elevations all slope downward from north to south. The elevation change on an east-west line is usually too small to measure using available data.

Study Area

The lakes in the study are all natural oxbows located in northwest Mississippi in the alluvial floodplain of the Mississippi River (Figure 1 and Table 1). Most of the Best Management Practices (BMPs) relevant the current study were implemented before Global Positioning System (GPS) units were in common use, and few records of the exact location of specific BMPs have survived to the present. Records for the types of BMPs implemented within each of the selected watersheds were available, though without precise locations. Although the non-specific nature of the BMP information does not lend itself to measuring the effectiveness of individual BMPs, the information is sufficient for the purposes of this study where the time and general extent of improvements are more important than specific BMP methodology and location. In the following sections, the studied lakes are described in order of increasing lake surface area.

Roundaway Lake. Located in Coahoma County, Mississippi, the Roundaway Lake watershed is composed of row-crop agriculture and a small percentage of aquaculture. Much of the land surrounding the lake was purchased by the current owners in the mid 1990s. At that time, field borders were raised and drop pipes were added to mitigate the direct discharge into the lake of eroded material caused by gully formation (Bowen Flowers, landowner; personal communication, 2009). North to south elevation along a 2.7 km (1.7 mi) transect centered on the lake varies by approximately 1 m (3 ft). Roundaway is the smallest of the lakes in the study and has the second smallest watershed area.

Beasley Lake. Located in Sunflower County, Mississippi, Beasley Lake is in a largely agricultural watershed that is approximately 67% row crops. Beasley is part of the Big Sunflower River watershed. The lake was included in the Mississippi Delta Management Systems Evaluation Area (MD-MSEA) project, whose main focus was to monitor changes in lake water quality as a function of management practice. As part of the study, slotted board risers, slotted inlets, and fescue and switchgrass buffers were added in the watershed during 1994-1996. During this time period, 70% reduction in suspended sediment was observed in the lake (Locke et al. 2008). Row crop production was decreased from 79% of the watershed to 67%, and erosion control measures, such as vegetated buffers and grade stabilization structures, were implemented. These changes affected nearly every part of the watershed and made this the most heavily modified of the watersheds studied. North to south elevation along a 1.8 km (1.1 mi) transect centered on the lake varies by approximately 2 m (6 ft).

Wolf Lake. Wolf Lake is located in northern Yazoo and southern Humphreys Counties in Mississippi. At the time of BMP implementation, the lake's watershed was 75% cropland, 7% aquaculture, 3% noncultivated agriculture, 1% residential, and 14% other land uses. There has been little change in land use since these numbers were tabulated, with a modest increase in residential (still estimated <2%) and a small decrease in cropland (Martin McGraw, Natural Resources Conservation Service, Soil Conservation Technician; personal communication, 2010). The main use of Wolf Lake is recreation. From 1996 to 1997, to alleviate pesticide and sediment impairments which caused listing in Mississippi's Nonpoint Source Management plan, a series of management practices were implemented. These included terrace systems, diversions, reduced tillage, conservation tillage, sediment control basins, winter cover crops, field borders, grassed waterways, grade stabilization structures, contour strip-cropping, and vegetative filter strips (MSWCC 1997b). The area surrounding Wolf Lake is characterized by extremely low relief, with roughly 1 m (3 ft) of elevation change along a 16 km (10 mi) north-south transect centered on the lake.

Moon Lake. Located in Coahoma County, Mississippi, Moon Lake's primary use is recreation. The watershed is dominated by agriculture, with 77% of the area in cropland and 4% pasture. In 1999, the following management practices were implemented to reduce runoff entering the lake from Philips Bayou: no-till cotton, soybeans, and grain sorghum, and grade stabilization on 13 ha (32 acres). Approximately 11% of the watershed had management practices applied (MDEQ 2002; MSWCC 1997a). North to south elevation along a 15.6 km (9.8 mi) transect centered on the lake varies by approximately 2 m (6 ft).

Lake Washington. The largest lake in the study, Lake Washington is in Washington County, Mississippi, and is primarily used for recreation. In 1990 and the following years, the Lake Washington watershed had numerous BMPs installed including filter strips, grass waterways, cover crops, grade stabilization structures, water control structures, permanent vegetative cover, and conservation tillage. These practices were installed as a result of EPA Project 319 funding; the majority of the BMPs were placed on the west side of the lake. Approximately 1,578 ha (3,900 acres) of cropland were converted to no-till and 364 ha (900 acres) to reduced-till for cotton, soybeans, grain sorghum, and corn. Fourteen grade stabilization structures were also installed along with grass filter strips, grassed waterways, and vegetation barriers along fields (USEPA 1994). North to south elevation along a 17.7 km (11.1 mi) transect centered on the lake varies by approximately 2 m (6 ft).

Results and Discussion

Figures 2-7 show the radioisotope data used to infer sedimentation rates, and Table 2 summarizes the findings. In each case, the depth chosen for measuring the slope of the ^{210}Pb data before and after watershed improvements was based on knowledge of the time periods for implementation of management practices.

Roundaway Lake. Roundaway Lake is the smallest lake in this study, which is reflected in the relatively high sedimentation rate (Dendy and Bolton 1976). There was a 33% reduction in sedimentation rate after raising field borders and installing drop-pipes in the mid 1990s (Figure 2A). The weighted mean ^{210}Pb-derived sedimentation rate for 1963-2009 of 2.2 cm/yr (0.9 in/yr) is in good agreement with the ^{137}Cs-derived range of 1.9 to 2.5 cm/yr (0.7 to 1.0 in/yr) (Figure 2B).

Beasley Lake. The most pronounced and clear reduction in sediment accumulation rates was observed in Beasley Lake. The erosion control and cropping practices in this watershed resulted in an approximate 76% decrease in sedimentation rate (Figure 3A). The weighted mean sedimentation rate of 1.8 cm/year (0.7 in/yr) for 1963-2009 is 28% higher than the upper limit for the ^{137}Cs-estimated range of 0.8 to 1.3 cm/yr (0.3 to 0.5 in/yr) (Figure B). The clear response of sedimentation rates in Beasley Lake is likely due to several factors. First, this watershed experienced extensive alteration in land use practices. Second, it is the second smallest lake in the study and has the smallest watershed, making the system more sensitive to change than larger watersheds.

Wolf Lake. The Wolf Lake data (Figure 4A) also indicate a clear change in sedimentation rate, with a reduction of approximately 81% in the years 1997-2009. However, there is a good deal of scatter in the data below the breakpoint, resulting in a large uncertainty in the calculated pre-BMP sedimentation rate. The ^{137}Cs data (Figure 4B) indicate that the core was not deep enough to capture the peak in ^{137}Cs activity; hence, it is only possible to conclude that the peak ^{137}Cs-activity was either at the deepest sample (148 cm (58.3 in)) or deeper, resulting in a sedimentation rate of at least 3.2 cm/yr (1.3 in/yr): (148/(2009-1963) = 3.2 cm/yr). The large number of data points for the Wolf Lake core is due to combining data from the two cores used for repeatability analysis. The degree of uncertainty in the ^{210}Pb-based sedimentation rate is not significantly improved when considering each core independently (see the Repeatability section below).

Moon Lake. There was not a clear change in sedimentation rate at any depth in Moon Lake (Figure 5A). The mean sedimentation rate of 0.8 cm/yr (0.3 in/yr) based on ^{210}Pb was in agreement with the ^{137}Cs-based sedimentation rate of 0.5 to 0.9 cm/yr (0.2 to 0.4 in/yr) (Figure 5B). Experimentation with breakpoints at various depths did not produce significantly different sedimentation rates at any depth. Reduction in erosion in this watershed was too small to produce a detectable change in sediment accumulation rates in Moon Lake. The size of the watershed (24,247 ha (60,000 acres)), the large fraction of the watershed in row-crop agriculture (77%), the relatively small fraction of area affected by the BMPs (11%), and the recent timeframe for the changes (10 years prior to sampling) all combined to make detection of a change in erosion rate difficult. It is likely that isolated areas within the watershed have experienced improved soil retention, but it may take either more time or additional BMPs to result in a change that can be observed in the lake.

Lake Washington. As the largest lake in the study, it should be expected that Lake Washington would have a relatively low sedimentation rate (Dendy and Bolton 1976). The ^{210}Pb data indicate 0.6 cm/yr (0.2 in/yr) (Figure 6A), but there is a large amount of scatter in the data, including the ^{137}Cs data (Figure 6B), indicating that the shallow sediments have experienced a degree of mixing since deposition. However, mixing indicated by the ^{137}Cs data appears to be limited to the upper 15 cm of sediment, after the deposition of sediments with peak ^{137}Cs-activity. Since ^{137}Cs-based sedimentation calculations are based solely on the depth of the peak activity, it is possible to get a reasonable estimate of average sediment accumulation rates here even though mixing of the uppermost sediments is evident. No clear change in sedimentation rate is apparent in the ^{210}Pb data, either due to the large degree of scatter, or because BMPs were not extensive enough to elicit a measurable change in sediment accumulation rate in this lake. Lakes the size of Lake Washington and larger may require more than 15 years or more extensive management practices before changes in erosion rate are detectable using sediment accumulation rates.

Repeatability

Figure 7 plots the ^{210}Pb data from the two cores from Wolf Lake separately in order to determine if the calculated sedimentation rates from one core can be reproduced in a second core. Wolf Lake core A (Figure 7A) does not have a well-defined breakpoint in ^{210}Pb slope, but, using the iterative method described above, a breakpoint that yielded a depth of overlying sediment that agreed with the known date of BMP implementation was found. The results from Wolf Lake core B (Figure 7B) clearly show a change in slope for shallow and deep samples, documenting a reduction in sediment accumulation rates, but scatter in the data makes precise determination of sedimentation rates problematic. Calculated sediment accumulation rates for the two cores are in good agreement for recent deposits at 1.0 ± 0.3 and 0.9 ± 0.6 cm/yr (0.4 ± 0.1 and 0.4 ± 0.2 in/yr, for A and B, respectively), but rates are divergent below the breakpoint at 4.3 ± 1.7 and 9.2 ± 4.3 cm/yr (1.7 ± 0.7 and 3.6 ± 1.7 in/yr). The depth for the breakpoint was also different, at 17.3 cm (6.8 in) in core A and 14.2 cm (5.6 in) in core B. This disparity is reduced by interpolating between points instead of hinging the breakpoint on a sampled depth, but the values are not reported here because the goal of this exercise was to determine the similarity of sedimentation rates from separate cores using the described method. The reduction in sediment accumulation rate is 78% based on the first core, and 90% based on the second.

General discussion

The size of the lake had a strong apparent effect on the results of this study, though firm conclusions cannot be drawn with a sample set of only five lakes. Clear changes in sedimentation rate were only observed for lakes with a surface area less than 900 ha (2,224 acres). The size of the lake also appeared to be more important than the size of the watershed; for example, Washington and Wolf have similar watershed areas, but a clear change in sedimentation rate was observed in only Wolf Lake. The ratio of watershed area to lake surface area may also be a useful predictor as shown in Table 1. Two of the three lakes displaying clear changes in sedimentation rate had the largest watershed/lake ratios (>30; Table 2). The exceptionally long and sinuous shape of Wolf Lake may result in much more direct surface runoff into the lake, which may outweigh the typical relationship between watershed and lake size.

Other factors besides erosion control measures, such as variation in precipitation, can also affect sediment delivery and sediment accumulation rates in downstream lakes. Daily precipitation data were obtained from the National Climate Data Center for five weather stations distributed across the study area (Figure 8; see Figure 1 for locations). The weather stations were selected to be as near the lakes in the study as possible; however, large local variations in rainfall make the direct application of rainfall data from a weather station several kilometers away problematic. For this reason, the rainfall data is used here to identify regional changes and long-term trends only. The plots on the left side of Figure 8 show the number of days each year that had rainfall amounts greater than two standard deviations above the mean rainfall for the period of record. The plots on the right side show annual total precipitation. If the observed decreases in sedimentation rate at Roundaway, Beasley, and Wolf Lakes were caused by fewer intense rainfall events, or less annual rainfall, this should be reflected by a decrease in average precipitation and intensity after 1990, particularly in the data from the Stoneville, Clarksdale, and Yazoo City weather stations.

The solid and dotted horizontal lines on each graph in Figure 8 represent the average annual precipitation or average annual number of high intensity rainfall events before and after 1990. In all cases, the average values before and after 1990 are nearly identical. In the three stations nearest Roundaway, Beasley, and Wolf Lakes, the post-1990 average values are equal to or higher than the pre-1990 averages for both total and high intensity rainfall (Figure 8A-F), effectively eliminating variation in precipitation as a cause of reduced sedimentation rates.

Summary and Conclusions

Sedimentation rates in five Mississippi Delta area oxbow lakes were used to assess the effectiveness of management practices implemented in their watersheds. Radioisotope methods and known dates of implementation were used together to find pre- and post-BMP sedimentation rates. Core samples were collected from lakes with a large range in surface and watershed area so that the effects of both on ability to detect changes in sedimentation rate could be assessed. Clear reductions in sediment accumulation rates were apparent in three of the five lakes. The specificity of the results in the study relative to particular erosion control measures was limited due to lack of precise location data for management practices. It is anticipated that, due to readily available handheld GPS products, more recent projects will have better location data that may enable direct comparison of the effectiveness of specific erosion control methods.

The size of the lake had a strong apparent effect on the results of this study, with smaller lakes showing much more response to BMP implementation. The ratio of watershed to lake surface area may also influence the extent to which erosion control measures impact sedimentation rates; two of the three lakes displaying clear changes in sedimentation rate had the largest watershed/lake ratios (>30; Table 2). Spatial variability and reproducibility were tested in Wolf Lake, and, although there was a disparity in the pre-BMP measured rates between two different cores, both cores clearly demonstrated substantial reductions in sediment delivered to the lake following BMP implementation.

For the three lakes that displayed changes in sedimentation rate, there was not an apparent regional reduction in annual cumulative rainfall, nor an increase in high intensity events that could account for the observed reductions in sedimentation rate.

Radioisotope dating was shown to be useful for documenting reductions in sedimentation rate resulting from management practices with known implementation dates in relatively small watersheds. When there is significant scatter in the data, it is not possible to determine the date of BMP implementation if not already known. If funds for post-implementation core sampling and radioisotope dating can be built into large erosion-control projects, there could be a much better chance of documenting the effectiveness of the work. There is great potential for improving the current state-of-the-art in erosion control while also increasing the credibility and accountability of individuals or agencies that have responsibility for planning and implementing large-scale watershed management practices.

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Table 1. Lake characteristics. Lakes are listed in order of size.

Lake	Latitude (N)	Longitude (W)	Typical surface area (ha)	Watershed area (ha)	Watershed/Lake (surface area ratio)
Roundaway	34° 1.252’	90° 35.742’	21	1,254	60
Beasley	33° 24.083’	90° 40.324’	25	915	37
Wolf	32° 55.639’	90° 27.997’	450	11,750	26
Moon	34° 27.412’	90° 31.152’	930	24,247	26
Washington	33° 2.531’	91° 02.467’	1260	10,995	9

Table 2. Sedimentation rates. Cores were collected in 2009. BMP completion dates are approximate.

Lake	^{210}Pb recent (cm/yr)	^{210}Pb before changes (cm/yr)	% Reduction	^{137}Cs (cm/yr)	BMP completion
Roundaway	1.6 ± 0.8	2.4 ± 0.5	33%	2.0-2.5	1995
Beasley	0.5 ± 0.1	2.1 ± 0.1	76%	0.8-1.3	1996
Wolf	1.1 ± 0.2	5.7 ± 1.7	81%	>3.2	1997
Moon	0.8 ± 0.3	n/a	n/a	0.5-0.9	1999
Washington	0.6 ± 0.2	n/a	n/a	0.2-0.5	1990

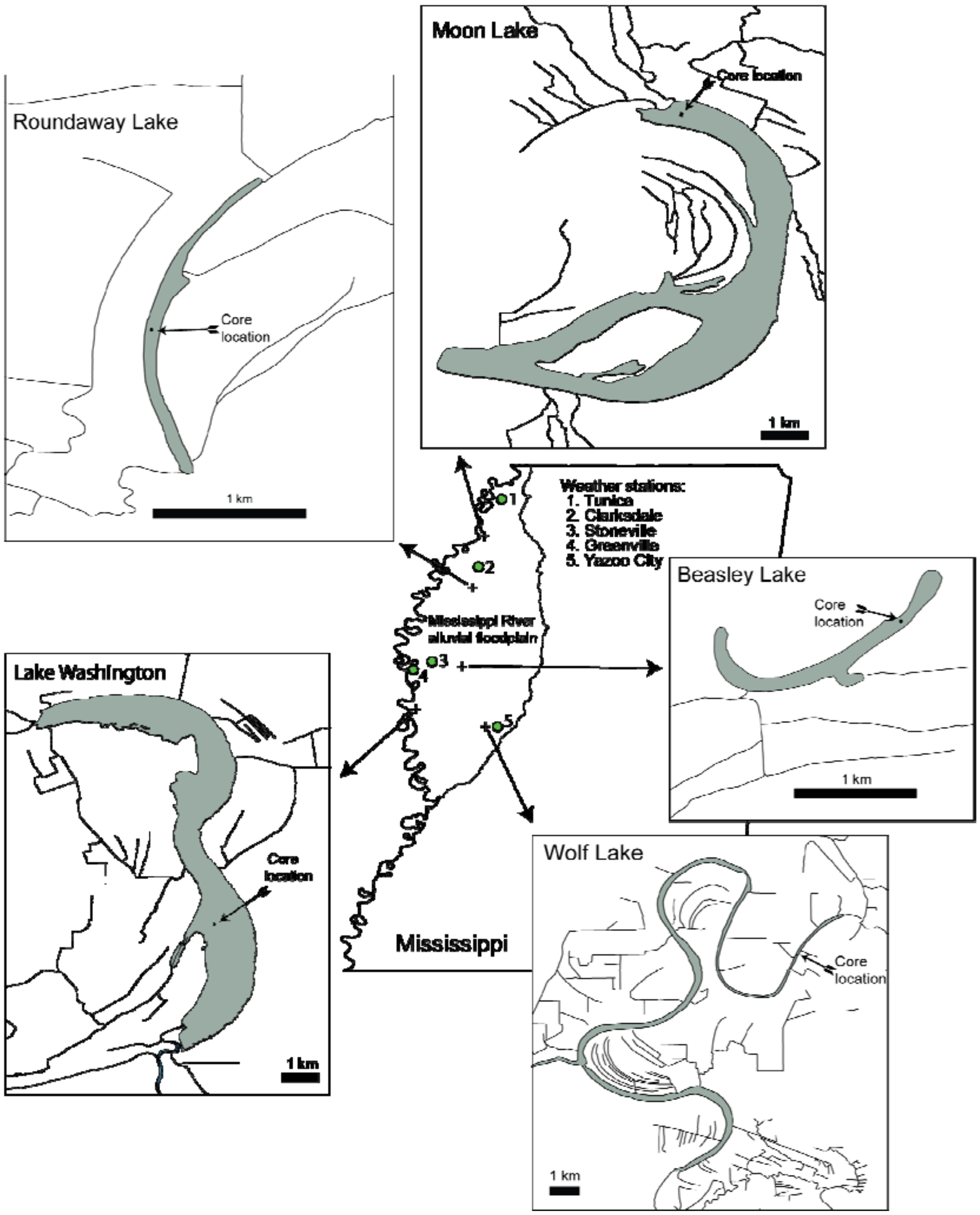

Figure 1. Locations of the five lakes under investigation and the weather stations from which rainfall data were obtained.

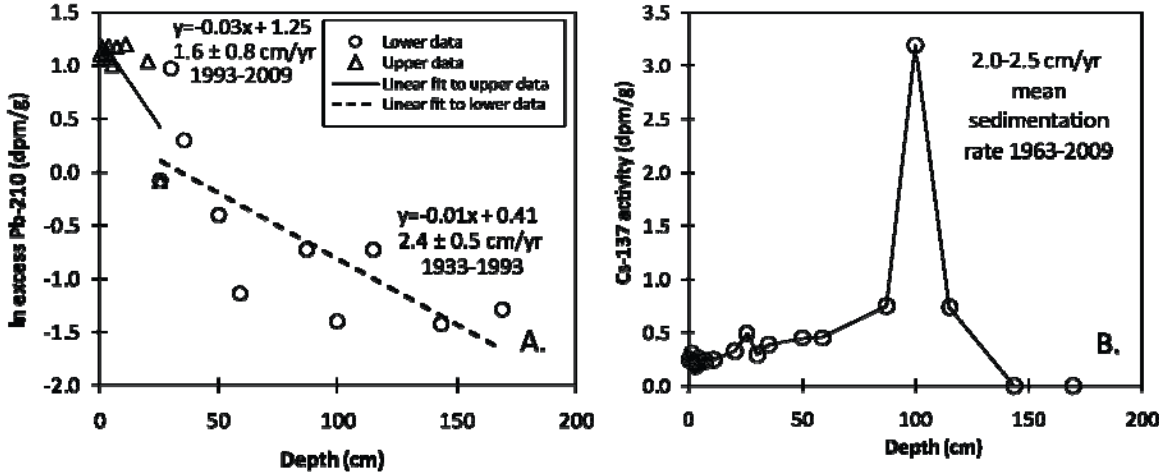

Figure 2. Data used to estimate sedimentation rates in Roundaway Lake: (A.) ^{210}Pb and (B.) ^{137}Cs.

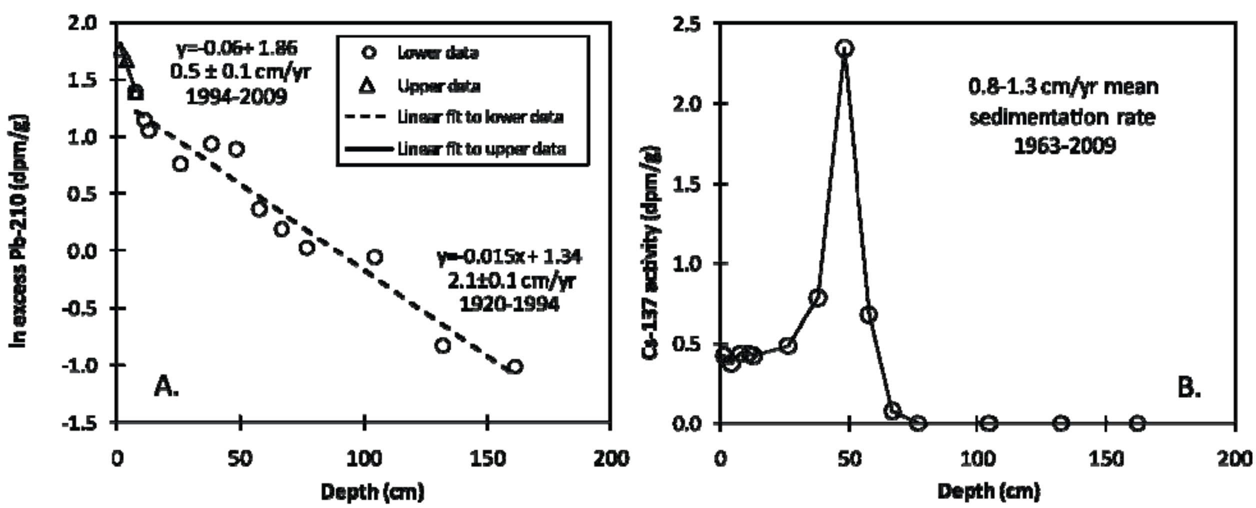

Figure 3. Data used to estimate sedimentation rates in Beasley Lake: (A.) ^{210}Pb and (B.) ^{137}Cs.

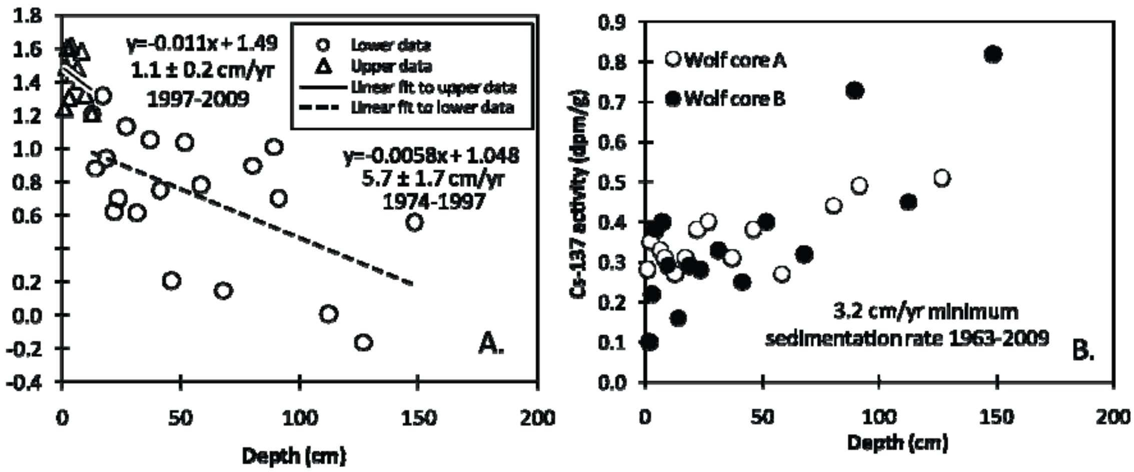

Figure 4. Data used to estimate sedimentation rates in Wolf Lake: (A.) ^{210}Pb and (B.) ^{137}Cs. Both plots contain combined data from Wolf Lake cores A and B, but they are not differentiated in Figure A because it obscures the visibility of the data markers at shallow depth. The ^{210}Pb data for each core is plotted separately in Figure 7.

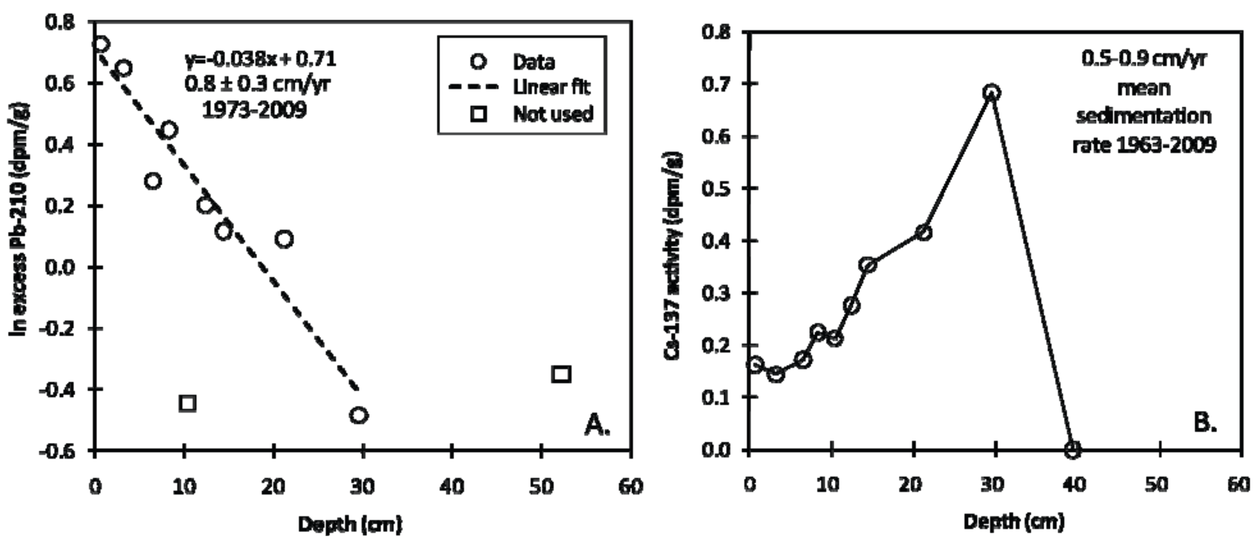

Figure 5. Data used to estimate sedimentation rates in Moon Lake: (A.) ^{210}Pb and (B.) ^{137}Cs. The slope does not appreciably change with or without the data points shown as squares in (A).

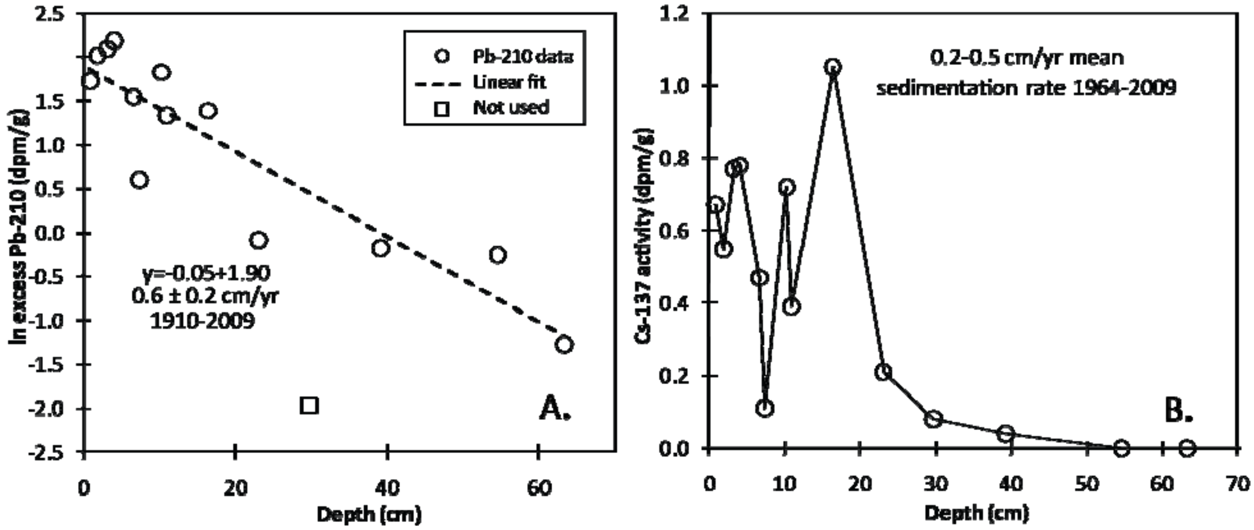

Figure 6. Data used to estimate sedimentation rates in Lake Washington: (A.) ^{210}Pb and (B.) ^{137}Cs.

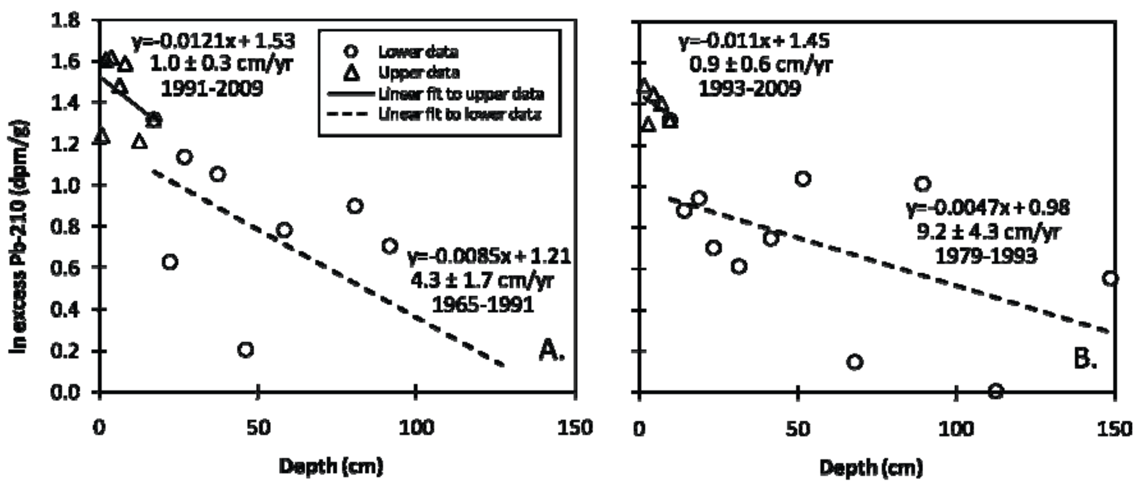

Figure 7. Wolf Lake sedimentation rates derived from (A.) core A and (B.) core B.

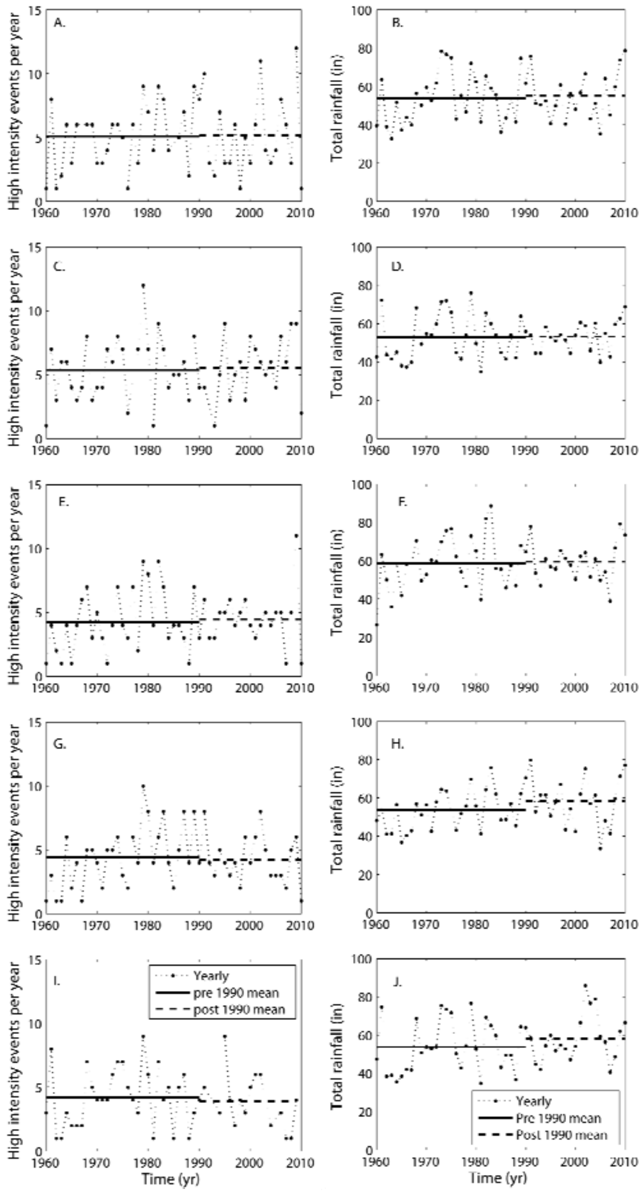

Figure 8. High intensity rainfall events (left side) and annual total rainfall (right side) for weather stations at: (A & B) Clarksdale; (C & D) Stoneville; (E & F) Yazoo City; (G & H) Tunica; and (I & J) Greenville . Horizontal lines represent the average values before 1990 (solid lines) and after 1990 (dotted lines). Locations of the stations relative to the lakes in the study are shown in Figure 1.

Influences of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain

Basic Information

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2. Dyer, J.L., Influences of Land Surface Characteristics on Precipitation over the Lower Mississippi Alluvial Plain, oral presentation at the 2009 Mississippi Water Resources Conference, August 5-7, 2009, Tunica, MS, in Proceedings, 14 pgs. http://www.wrri.msstate.edu/pdf/2009_wrri_proceedings.pdf
3. Dyer, J.L., 2009, Evaluation of Surface and Radar Estimated Precipitation Data Sources over the Lower Mississippi River Alluvial Plain, Physical Geography, 30, 430-452.
4. Dyer, J.L., Influence of Land Surface/Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain, a status report presented to the Mississippi Water Resources Research Institute Advisory Board, November 17, 2009, Mississippi State, MS.
5. Dyer, J.L., 2010, Four-dimensional visualization and analysis of convective rainfall generation along an abrupt land use/land cover boundary in northwest Mississippi, presented at the 91st Annual Meeting / 24th Conference on Hydrology, American Meteorological Society, Atlanta, GA.
6. Dyer, J.L., Effect of land cover boundaries on warm-season precipitation generation in Northwest Mississippi, presented at 2010 Mississippi Water Resources Conference, November 3-5, 2010, Bay St. Louis, MS, http://www.wrri.msstate.edu/conference/abstract.asp?id=1032.
7. Dyer, J.L., Influence of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain, status report presented to the Mississippi Water Resources Research Institute Advisory Board, Mississippi State, MS, November 9, 2010.
8. Dyer, J.L., 2010, Influence of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain, final technical report submitted, Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 32 pgs.
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accepted.

Mississippi Water Resources Research Institute (MWRRI) / US Geological Survey

Final Report for Award Number 2009MS85B

Influences of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain

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Abstract

The lower Mississippi River alluvial valley in southeast Arkansas, northeast Louisiana, and northwest Mississippi is characterized by widespread agriculture with few urban areas. Land use is predominantly cultivated cropland with minimal topographic variation; however, the eastern edge of the alluvial valley is defined by a rapid, though small, change in elevation into a heavily forested landscape. This change in land use / land cover has been shown to potentially enhance precipitation through generation of a weak mesoscale convective boundary. This project defines the causes and influence of the land surface on associated precipitation processes by simulating a convective rainfall event that was influenced by regional surface features. Analysis was conducted using a high-resolution simulated dataset generated by the Weather Research and Forecasting (WRF) model. Results show that the strongest uplift coincides with an abrupt low-level thermal boundary, developed primarily by a rapid change from sensible to latent heat flux relative to the agricultural and forested areas, respectively. Additionally, surface heating over the cultivated landscape appears to destabilize the boundary layer, with precipitation occurring as air is advected across the land cover boundary and the associated thermal gradient. This information can be used to define and predict surface-influenced convective precipitation along agricultural boundaries in other regions where the synoptic environment is weak.

1. Project Overview

Soil type and vegetation play a key role in determining the dynamics of energy and moisture transport into the atmospheric boundary layer through spatial variations in evapotranspiration, albedo, and surface heat fluxes (Hong et al., 1995; Segal et al., 1988; Ookouchi et al., 1984; Rabin et al., 1990; Mahfouf et al., 1987; Boyles et al., 2007). These effects are well documented, and can occur in various climate zones given benign synoptic forcing. Research has shown that anthropogenic modification of spatial boundaries in land use / land cover through agricultural practices can have an influence on regional weather variability through these processes (Brown and Arnold, 1998). Additionally, agricultural land use can influence the dynamics of the boundary layer through variations in surface roughness over the growing season, effectively modifying existing sub-synoptic and mesoscale flow regimes by varying the intensity of turbulent mixing through the radix layer.

The energy, moisture, and turbulent fluxes all have strong influences on the generation and strength of mesoscale circulations, which can affect precipitation generation. As a result, variations in land use and/or soil type can lead to changes in regional precipitation patterns and associated water resources (Anthes, 1984). Regarding soil-type interfaces, several studies have demonstrated the role of the sand-clay soil boundary in eastern North Carolina (a.k.a., the "Sandhill Effect") on mesoscale surface convergence and convective precipitation (Boyles et al., 2007; Koch and Ray, 1997). Similar soil contrasts, along with distinct vegetation boundaries, exist within the lower Mississippi River alluvial valley in northwest Mississippi (known locally as the Mississippi Delta), and results from Dyer (2008) indicate that precipitation patterns in and around the Mississippi Delta may be influenced by distinct horizontal boundaries in soil type and/or land cover. Additionally, studies have shown that abnormal temperature variations in the region exist as a result of spatial variations in soil and vegetation (Raymond et al., 1994; Brown and Wax, 2007). These temperature effects could be an indicator of possible boundary layer modification through surface influences, resulting in the generation of mesoscale circulations and related localized precipitation.

Although the modification of atmospheric properties through surface characteristics occurs on a diurnal scale, seasonal variations in land cover and synoptic conditions play a role in the strength and extent of the influence. As a result, it is necessary to study the daily evolution of mesoscale convective processes while keeping in context the seasonal conditions of the region of interest. In general, the spatial extent of surface influenced atmospheric processes is of the same scale as the land cover discontinuity driving the circulation, with the advection of atmospheric features (i.e., cloud cover, precipitation, etc.) dependent on the regional synoptic wind field conditions. The modification of rainfall patterns over north Mississippi is on the order of 100 km downwind of the Mississippi Delta boundary (Dyer, 2008), which indicates that local influences play a dominant role in determining the circulation patterns related to the convective development. However, to better define the local variability in surface and atmospheric properties it is necessary to determine the characteristic spatial and temporal scale of the land cover boundary and regional meteorological conditions.

The primary objective of this study is to identify the surface influences on mesoscale convective precipitation generation in northwest Mississippi during the warm season, especially along the eastern boundary of the lower Mississippi River alluvial valley (a.k.a., Mississippi Delta). Due to the highly agricultural characteristic of the landscape in this region and the associated sensitivity to water resources, it is important to identify potential causes for precipitation modification due to land surface characteristics during the warm season when mesoscale processes dominate and water availability is critical. The study employs numerical weather model simulations to identify surface and lower atmospheric processes related to convective precipitation generation. Results of this project provide detailed information regarding precipitation patterns over the Mississippi Delta during the warm season, allowing agriculture and water resource managers to make more accurate local-scale predictions and assessments of water supply and availability.

2. Data and Methods

To better understand the influence of land cover and/or soil boundaries on rainfall distribution in the Mississippi Delta, it is necessary to perform an analysis of convective forcing mechanisms and the associated precipitation generation. Due to the lack of high-resolution observation data in the region, this type of study is best performed through numerical modeling;

therefore, this project utilizes the Weather Research and Forecasting (WRF; Skamarock et al., 2005) model to simulate regional surface and atmospheric mechanisms and processes related to rainfall generation. WRF has been used in various research applications dealing with convective systems and initiation (Done et al., 2004; Schumacher and Johnson, 2005; Trier et al., 2006; Clark et al., 2007; Lim et al., 2008) as well as precipitation distribution and prediction (Miller and Weisman, 2002; Kusaka et al., 2005). Research applications using WRF to simulate heavy precipitation related to flooding have also been conducted in various regions around the world, including Taiwan (Lin et al., 2005) and Texas (Lowrey and Yang, 2008). Additionally, modeling studies have been carried out in various locations to examine the sensitivity of mesoscale circulations to surface characteristics (Mahfouf et al., 1987; Boyles et al., 2007; Hong et al., 1995).

Dyer (2010), using observed and remotely-sensed cloud and precipitation data, showed that precipitation over the southeast US, and the Mississippi Delta in particular, shows a distinct seasonal pattern such that the warm season is dominated by surface-initiated convection driven by small-scale thermodynamic boundaries. The regional variations in precipitation patterns were on the order of 100-km relative to the Mississippi Delta, with convective initiation and rainfall generation occurring on a diurnal temporal scale. However, the surface discontinuity and related convective circulation is on the order of 10-km; therefore, high spatial resolution data is required to assess the influence of surface properties on atmospheric processes.

To analyze the atmospheric mechanisms associated with this pattern, a day was chosen (September 9, 2006) that displayed regional convective precipitation generation and weak synoptic conditions (details on related atmospheric conditions are included in Section 4.1), indicating that the precipitation was a result of near-surface thermodynamic forcing mechanisms. For the study day, WRF was run for a 24-hour period beginning at 0000 LST with 30-minute temporal resolution over a domain centered on the eastern boundary of the Mississippi Delta (Figure 1). The model surface and atmospheric horizontal resolution was set at 3-km with 60 vertical atmospheric levels (logarithmic from 1013 hPa – 100 hPa), which allowed for adequate simulation of convective processes without the need for a convective parameterization scheme. Initial and boundary conditions were provided by the North American Regional Reanalysis (NARR) dataset, which has a 32 km horizontal resolution, 50 hPa vertical resolution, and 3 hour temporal resolution (Mesinger et al., 2005). Subsequent WRF model parameterizations were chosen to best simulate warm-season, surface-based, mesoscale processes. These include the Lin et al. (1983) microphysics scheme, the Mellor-Yamada-Janjic boundary layer scheme, the 4-layer Noah land surface model (Chen and Dudhia, 2001), the rapid radiative transfer model (RRTM) scheme for longwave radiation (Mlawer et al., 1997), and the Dudhia (1989) scheme for shortwave radiation. The time step for the radiation schemes was set at 5 minutes.

Although other parameterizations schemes may lead to different model responses, a sensitivity analysis using various parameterizations was beyond the scope of this study. However, Trier et al. (2010) showed that considerable uncertainty exists in the strength and timing of convective precipitation generation within the WRF model during events influenced by surface-atmosphere energy and moisture exchanges. This uncertainty is based on the turbulent surface exchange strength, which is related to vegetation height and surface roughness; therefore, future research plans include an investigation of WRF using a parameter ensemble approach to verify which schemes and surface exchanges coefficients are most applicable for simulation of convective precipitation in the southeast US.

Verification of the WRF simulations is accomplished using a variety of observed and estimated data sources. Precipitation data are verified against 4x4 km precipitation estimates from the Multi-Sensor Precipitation Estimator (MPE) algorithm, which are derived from hourly WSR-88D data (Weather Surveillance Radar – 1988 Doppler) and hourly surface-based observations from the hydrometeorological automated data system (HADS) network (Fulton, 2002). Simulated cloud cover is compared with visible imagery from the Geostationary Operational Environmental Satellite (GOES) platform, while surface meteorological characteristics and soil properties from Soil Climate Analysis Network (SCAN) stations in and adjacent to the Mississippi Delta are used to verify related WRF-simulated variables (U.S. Department of Agriculture, 2010; Figure 1).

3. Project Results

3.1 Verification of WRF Simulation

Cloud cover patterns over the study area for the morning of September 9, 2006 (1000 LST) initially showed generally clear conditions over Arkansas and northern Louisiana with an increase in convective cloud cover to the south and east (Figure 2a). Additionally, a thin line of convective clouds were apparent along the southeastern boundary of the Mississippi Delta. The WRF simulated cloud cover reflects this pattern well, showing an increase in cloud cover to the southeast of the study area and a line of clouds along the eastern boundary of the Mississippi Delta (Figure 2b).

As the day progresses, observed cloud cover becomes more pronounced along the eastern boundary of the Mississippi Delta and east along the Mississippi/Alabama border, with the extent of the cloud area increasing as convection strengthens (Figure 2c,e). This pattern is maintained through the day, such that by late afternoon (1600 LST; Figure 2g) the most dense cloud cover roughly exists along the eastern edge of the Mississippi Delta and northwestern Alabama. Although the WRF simulated cloud patterns show some variability relative to the observed cloud cover, the same general patterns exist. At 1200 LST (Figure 2d) the most dense cloud cover follows a line roughly parallel to the Mississippi/Alabama border. As the day progresses, a secondary line of convective cloud cover is apparent along the eastern edge of the Mississippi Delta with a definite clear area becoming more defined through the afternoon (Figure 2f,h).

The agreement in the observed and simulated cloud cover over the Mississippi/Alabama border and the eastern edge of the Mississippi Delta indicates that WRF is able to recognize and produce reliable convective cloud patterns over the study period. This is critical due to the importance of the cloud cover in the recognition of a convective mesoscale boundary over the study area, as well as the importance of cloud location and extent in association with the simulated surface heat fluxes.

With regard to precipitation patterns, early in the day on September 9, 2006 both the observed and simulated precipitation patterns agree well, despite the minimal amount and extent of rainfall (Figure 3a-b). Since the rainfall associated with the mesoscale convective boundary initiated along the eastern boundary of the Mississippi Delta is of primary interest in this study, it is critical that the initial timing and location of the precipitation be simulated well. By noon on the study day, the observed precipitation changes little; however, the WRF simulated precipitation patterns begin to show some deviation (Figure 3c-d). Although the rainfall along the Mississippi Delta boundary is maintained, scattered rainfall is generated towards the east that is not mirrored in the observed record. The reason for the region of enhanced rainfall may be associated with false convective initiation in the region of maximum low-level moisture advection, which is reflected in the simulated cloud cover at the same time period (Figure 2d).

As the afternoon progresses the region of enhanced simulated rainfall to the east of the study area is maintained, although the extent continually decreases (Figure 3f,h). More important, however, is the continuation of rainfall along the eastern boundary of the Mississippi Delta and the lack of rainfall to the west of the study area. The multi-sensor precipitation estimates show an enhancement of rainfall intensity and extent along the eastern boundary of the study area through the day, with additional precipitation in northwest Alabama late in the afternoon (Figure 3e,g). Although the WRF simulation indicates a precipitation boundary along the Mississippi Delta boundary, the rainfall in northeastern Mississippi and northwestern Alabama is maintained throughout the day. The exact reasons for this early initiation of precipitation to the east of the study area is likely due to early initiation of convection through enhanced low-level moisture inflow within the model domain. However, the agreement between simulated and observed precipitation patterns along the eastern boundary of the Mississippi Delta is strong enough to accept the WRF simulated atmospheric conditions and continue with further analysis.

Verification of WRF simulated meteorological and surface conditions at select points over the study region using information from SCAN stations shows that near-surface conditions are relatively well resolved (Figure 4a-b). Although the agreement between the observed and modeled time series of temperature and dew point do not match exactly, the relative pattern and magnitude of the variables is maintained over the course of the study period. Specifically, the slightly lower temperature and higher dew point over the forested site relative to the sites within the Mississippi Delta indicate that the simulated surface energy and moisture fluxes are representative of actual conditions.

An examination of soil temperature and moisture shows that although the relative patterns between the simulated and observed data are in agreement, there is some discrepancy in the magnitude (Figure 4c-d). However, it should be noted that the values used for verification are not the same, such that the observed values from the SCAN sites are for soil conditions at 2-cm, while the WRF simulated values reflect average soil conditions from 2 – 10cm. As a result, the general patterns of the time series should match while the magnitudes may be substantially different. The graph of soil temperature (Figure 4c) shows that both the observed and simulated time series show the same relative minimum in the early morning and maximum at sundown, which is reasonable. Additionally, despite the difference in magnitude, neither data source shows much variation in soil moisture over the time period (Figure 4d). These results provide verification that the WRF model is satisfactorily representing soil temperature and moisture patterns over the study period; however, due to the difference in values being compared (2-cm vs. 2-10 cm average), the magnitude of the simulated values cannot be readily verified.

3.2 Synoptic Overview

The day used in this study, September 9, 2006, was previously defined as synoptically benign by Dyer (2010) based on low-level and mid-level wind speeds from regional sounding data. Under conditions where dynamic lifting mechanisms are negligible, convective precipitation is expected to be generated primarily by mesoscale thermodynamic boundaries set up by differential energy and moisture fluxes at the surface. However, the ability for pre-existing boundaries such as outflow boundaries or dry lines to trigger convection can make analysis of surface influences on atmospheric properties difficult. As such, even when synoptic forcing mechanisms are weak the complexity and limited scale of mesoscale convective processes makes it difficult to accurately define the location and timing of precipitation in response to surface energy fluxes.

To verify that the study period was characterized by weak regional dynamic forcing mechanisms with no pre-existing moisture or thermal boundaries, it is necessary to diagnose the general atmospheric conditions over the region. Using the 32-km North American Regional Reanalysis (NARR) dataset, meteorological characteristics at the surface, 850-hPa, and 300-hPa were analyzed to show that conditions on and prior to September 9, 2006 over the lower Mississippi River valley were susceptible to surface energy and moisture influences, especially along the eastern edge of the Mississippi Delta.

Although surface and atmospheric conditions over the study region show considerable variability during the warm season, September 9, 2006 showed minimal influence from synoptic or pre-existing mesoscale forcing mechanisms. Several days prior to the study period an upper-level trough moved across the study region (Figure 5 a-b), followed by a zonal flow pattern over the lower Mississippi river valley on September 8-9 (Figure 5c-d). Near the end of the study period a weak jet max developed to the west of the Mississippi Delta (Figure 5d). Although the dynamic lifting mechanisms associated with this upper-level pattern on September 9, 2006 are not strong enough to generate low-level vertical motion (not shown), the upper-level divergence pattern could help to enhance surface-based convection by helping to remove mass from the atmospheric column. As a result, the upper-level synoptic features during the study period do not appear to be the source of the surface-based convection, but may play a role in the maintenance of convective cells generated through other mechanisms.

Low-level synoptic conditions prior to the study period are roughly barotropic, with flow from the north-east on September 6 (Figure 6a) weakening through September 7 (Figure 6b). Wind and temperature patterns from September 8-9 (Figure 6c-d) show a gradual transition to south-southeasterly flow over the study region, leading to low-level warm air advection over the lower Mississippi River valley. By the evening of September 9 a slight zonal temperature gradient was in place along the eastern edge of the Mississippi Delta (Figure 6d) due to the advection of warm air to the west over Arkansas and northern Louisiana. It is possible that the low-level temperature gradient is the cause of the surface based convection during the study period; however, the orientation of this gradient along the eastern boundary of the Mississippi Delta could be a result of surface energy and/or moisture fluxes influencing atmospheric conditions. Although the cause and effect of this pattern is difficult to define using the 32-km synoptic data, it is necessary to look at regional surface conditions to verify that surface and low-level patterns coincide.

As with the wind field at 850-hPa, surface flow on September 8 – 9 is south-southeasterly across the lower Mississippi River valley (Figure 7). However, despite the southerly flow there is an area of relatively warm, dry air to the northwest of the Mississippi Delta on September 8 (Figure 7a,c) that decreases in extent into September 9 (Figure 7b,d). This area is evident at 850-hPa on September 9 (Figure 6d), where the eastern edge of the moisture and temperature gradient closely follows the edge of the Mississippi Delta at the surface. Interestingly, although the spatial extent of the warm, dry low-level air mass changes considerably from September 8 to 9, the gradient at the surface remains relatively fixed along the eastern boundary of the Mississippi Delta. This implies that surface conditions along the boundary of the Mississippi Delta are influencing atmospheric conditions on and prior to September 9, and that pre-existing synoptic and/or mesoscale boundaries are most likely not responsible for the generation of convective precipitation during the study period.

Precipitation patterns for the days leading up to September 9, 2006 show normal warm-season scattered rainfall over the study region (not shown); however, none of the rainfall appears to be of a high enough magnitude to modify soil moisture conditions along the Mississippi Delta boundary. As a result, the modification of surface soil moisture gradients based on rainfall leading up to September 9, 2006 is considered minimal. It is interesting to note, however, that precipitation patterns for the days leading up to September 9 show a general lack of rainfall over the Mississippi Delta and a regional maximum directly to the east along the Mississippi-Alabama border. This supports the argument that convective boundaries developing due to surface heterogeneities in northwest Mississippi are influencing local precipitation generation.

3.3 Analysis of WRF Simulation

Analysis of meteorological conditions using the 32-km NARR dataset indicates that surface characteristics within the Mississippi Delta may be influencing low-level atmospheric properties; therefore, it is necessary to utilize the 3-km WRF simulation to identify and analyze the local-scale factors causing this influence. Specifically, atmospheric factors related to vertical thermodynamic stability over the study region must be investigated to define the mechanisms responsible for the initiation of convection and precipitation generation.

The first indication of surface influences on lower atmospheric processes over northwest Mississippi on September 9, 2006 occurs as differential surface heating within the lower

Mississippi River valley causes near-surface (1000-hPa) air temperatures to increase relative to adjacent regions in the early afternoon (1400 LST; Figure 8a). At the same time, moisture advection from southeasterly surface winds lead to a relatively tight low-level humidity gradient along the eastern boundary of the Mississippi Delta (Figure 8b). The same general thermal and moisture pattern exists at 850-hPa (Figure 8c-d); however, the area of highest temperatures at this level covers a smaller area over the Mississippi-Louisiana border and west-central Mississippi. As a result, the thermal gradient to the east becomes weaker but is more confined to the central Mississippi Delta. Likewise, the moisture gradient becomes more clearly defined along the eastern border of the Mississippi Delta.

Further aloft at the 700-hPa level the thermal pattern over the study region is reversed, such that there is a temperature minimum over the lower Mississippi River valley with a rapid increase to the east and west (Figure 8e). This change in horizontal temperature gradient, where the relative position of the gradient remains stationary while the direction of the gradient changes with height, implies that there is a surface influence over the region driving the low-level energy flux and associated thermal patterns. If advective processes were the cause of the temperature gradient there would most likely be a change in position with height dependent on the velocity of the horizontal winds, while the relative strength of the gradient would be based on upwind thermal features.

Regarding the moisture patterns over the study region, the gradient at 700-hPa is shifted to the west relative to the lower levels (Figure 8f), being roughly positioned along the western edge of the region of cooler air over the lower Mississippi River valley. In fact, the thermal and moisture gradients at 700-hPa are closely aligned in southeast Arkansas, which could indicate that the strength of the surface influence on lower atmospheric properties is beginning to weaken while the influence of the southeasterly flow and moisture advection is beginning to dominate. It should be noted that convective cloud cover was observed and simulated to the east of the Mississippi Delta by 1400 LST on the study day (Figure 2e-f), indicating that convective processes caused surface moisture to be moved vertically, thereby increasing the lower-level humidity values and horizontal moisture advection over the Mississippi Delta.

The warm, dry conditions at the surface over the Mississippi Delta on September 9, 2006 along with warm, moist air aloft indicates a statically stable atmospheric column; therefore, convective initiation required either an external triggering mechanism or a change in surface and/or low-level atmospheric conditions. For the study period of September 9, 2006, both of these conditions likely come about due to modification of atmospheric properties through surface heat fluxes. In general, the lower Mississippi River alluvial valley is characterized by dark, fertile clay soils and low cropland, while vegetation to the east consists of relatively dense broadleaf and evergreen forests in loamy soils (Figure 1). September is near the end of the growing season in the region; therefore, there is a mix of harvested and non-harvested crops. Additionally, local water resource management requires an end to agricultural irrigation in August (Pennington, 2008). As a result, the amount of evapotranspiration over the Mississippi Delta is much lower than that over the surrounding forested land, leading to considerable variations in the surface heat fluxes.

Figure 9 shows the relatively stark contrast in the sensible and latent heat flux between the lower Mississippi River valley and adjacent regions during the course of the day on September 9, 2006. Even in the morning hours there is a noticeable minimum in the latent heat flux over the valley, which becomes more pronounced through the afternoon. The opposite is true with the sensible heat flux, which shows a general maximum over the lower Mississippi River valley from late morning through early afternoon when solar heating is greatest. The relatively cloud-free conditions over the Mississippi Delta exacerbate this pattern by maximizing the surface heating over the area, thereby strengthening the gradient along the eastern border of the Mississippi Delta where scattered cloud cover exists beginning in the early afternoon.

The ramifications of a higher sensible heat flux in the Mississippi Delta relative to surrounding areas is that surface temperatures will increase faster since there is less evapotranspiration to offset the radiation flux. As a result, lower atmospheric temperatures over the cultivated alluvial valley will increase relative to surrounding areas, causing a dome of warm air to develop due to decreased evapotranspiration over the agricultural surfaces relative to the forested lands to the east. This phenomenon is minimized in the morning when differential surface heating is minimized (Figure 10a), but is easily recognized in the early afternoon once the surface heat fluxes have intensified (Figure 10b).

This dome of warm air can act to destabilize near-surface air advected from outside the region, as is the case for the September 9, 2006 study period where southeasterly flow exists in the lower levels. The relatively warm air over the alluvial valley has a dominant influence during the late morning and early afternoon, as seen by the elevated low-level temperatures (Figure 8a,c). As convection initiates along this boundary, low-level moisture within the boundary layer from the east is utilized for latent heat release and precipitation generation, leading to deeper convection and eventually localized convective rainfall.

In addition to convective uplift due to moisture advection and low-level thermal boundaries, small-scale dynamic forcing is evident along the eastern edge of the Mississippi Delta in the form of near-surface speed confluence (see wind vectors in Figure 8b). The confluence is strongest in late morning, which is likely a result of a deepening of the boundary layer over the Mississippi Delta region through the early afternoon causing a decrease in local winds due to turbulent mixing. However, the combination of the thermodynamic and dynamic factors combines to cause low-level convection to intensify along the eastern Mississippi Delta interface before the initiation of a convective precipitation boundary in the afternoon.

While the southeasterly low-level flow causes near-surface air to become unstable along the eastern boundary of the Mississippi Delta where the positive thermal gradient is strongest, westerly flow aloft acts to advect the convective cells and associated precipitation to the east (Figure 8f). The westerly flow also augments the export of mass from the study area as the convective boundary develops, helping to strengthen and maintain the localized convection and vertical energy and moisture transport. This indirectly leads to an easterly transport of moisture from the study area, which can be considered a source of interbasin water transport.

4. Conclusions

The lower Mississippi River alluvial valley, known regionally as the Mississippi Delta, is characterized by widespread agricultural vegetation and clayey soils, while areas adjacent are heavily forested with loamy soils (Figure 1). The abrupt transition between the surface types leads to high spatial variations in the local energy and moisture balance, which plays a role in the intensity of the sensible and latent heat fluxes due to variations in evapotranspiration and albedo. On days when large-scale synoptic wind speeds are weak, vertical development is largely driven by low-level thermodynamic mechanisms related to these heat fluxes; therefore, the influence of surface conditions on atmospheric processes is substantial.

As shown in this project, local discontinuities in near-surface atmospheric properties during periods of benign synoptic forcing can lead to the development of mesoscale convective boundaries and localized precipitation. However, the specific role of surface conditions in the timing and extent of the convection and convective precipitation over the Mississippi Delta is not well understood. Using the Weather Research and Forecasting (WRF) model, a high resolution simulation was done for September 9, 2006, a day characterized as having weak synoptic conditions and the development of convective precipitation along the eastern boundary of the Mississippi Delta. This information was used to define and describe the surface characteristics responsible for modification of lower atmospheric properties and the associated influence on the development of a mesoscale convective boundary.

Results of the WRF simulation indicate that spatial variations in the sensible and latent heat fluxes relative to areas inside and adjacent to the Mississippi Delta are primarily responsible for atmospheric modification through surface processes. Specifically, a relatively high sensible heat flux inside the Mississippi Delta led to the development of a low-level region of warm air, while high latent heat values to the east over the forested regions helped to maintain a thermal gradient along the boundary of the study area. The thermal gradient was most intense in the early afternoon near the surface (1400 LST), covering most of the lower Mississippi River alluvial valley in northwest Mississippi and southeast Arkansas. The spatial extent of the dome of warm air decreased with height before reversing direction at 700 hPa, at which point the atmospheric temperatures were lower over the Mississippi Delta relative to adjacent regions.

Low-level southeasterly flow interacting with the horizontal thermal gradient near the surface caused a decrease in the vertical static stability over the region, which was augmented by the rapid decrease in atmospheric temperatures with height over the study area. Increased moisture advection along with the development of a mesoscale convergence boundary strengthened the convection along the eastern edge of the Mississippi Delta, leading to deep convection and the generation of convective rainfall. Subsequent westerly flow in the mid-levels during the study period acted to transport the convective cloud cover and associated precipitation to the east, effectively leading to dry conditions over the study area as the moisture was transported eastward.

The direct implications of the surface-based modification of atmospheric properties shown in this study include an indication of regional climate modification due to local anthropogenic causes. The transition from forest to agricultural vegetation over the Mississippi Delta directly affects the energy and moisture fluxes into the lower atmosphere, leading to variations in the patterns of warm season precipitation generation. In essence, the development of a mesoscale convective boundary along the eastern edge of the Mississippi Delta allows for an atmospheric pathway for interbasin water transport. This leads to a net removal of moisture from the agricultural region due to increased evapotranspiration and decreased precipitation. Although the use of a single day to study the influence of surface characteristics on convective rainfall generation does not take into account seasonal or annual variations in land cover or atmospheric properties, the fact that warm season surface conditions can modify local precipitation patterns introduces an area of future research that is critically important to agricultural and water resource managers.

The results of this study show that land surface incongruities, such as soil and vegetation boundaries, can cause horizontal variations in the latent and sensible heat fluxes large enough to influence surface-based atmospheric convection. Such is the case over the lower Mississippi River alluvial plain, where low-level moisture advection from the southeast, combined with an increased sensible heat flux over the Mississippi Delta, leads to convective precipitation initiation. This process is similar to that of the urban heat island, although it is often of a larger extent due to the greater extent of rural and agricultural areas throughout the US. Such precipitation modifications, although minimal relative to mean annual precipitation, could lead to variations in warm-season rainfall distribution. This may potentially lead to water resource issues due to the sensitivity of agriculture to local-scale precipitation patterns during the warm season.

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Figures

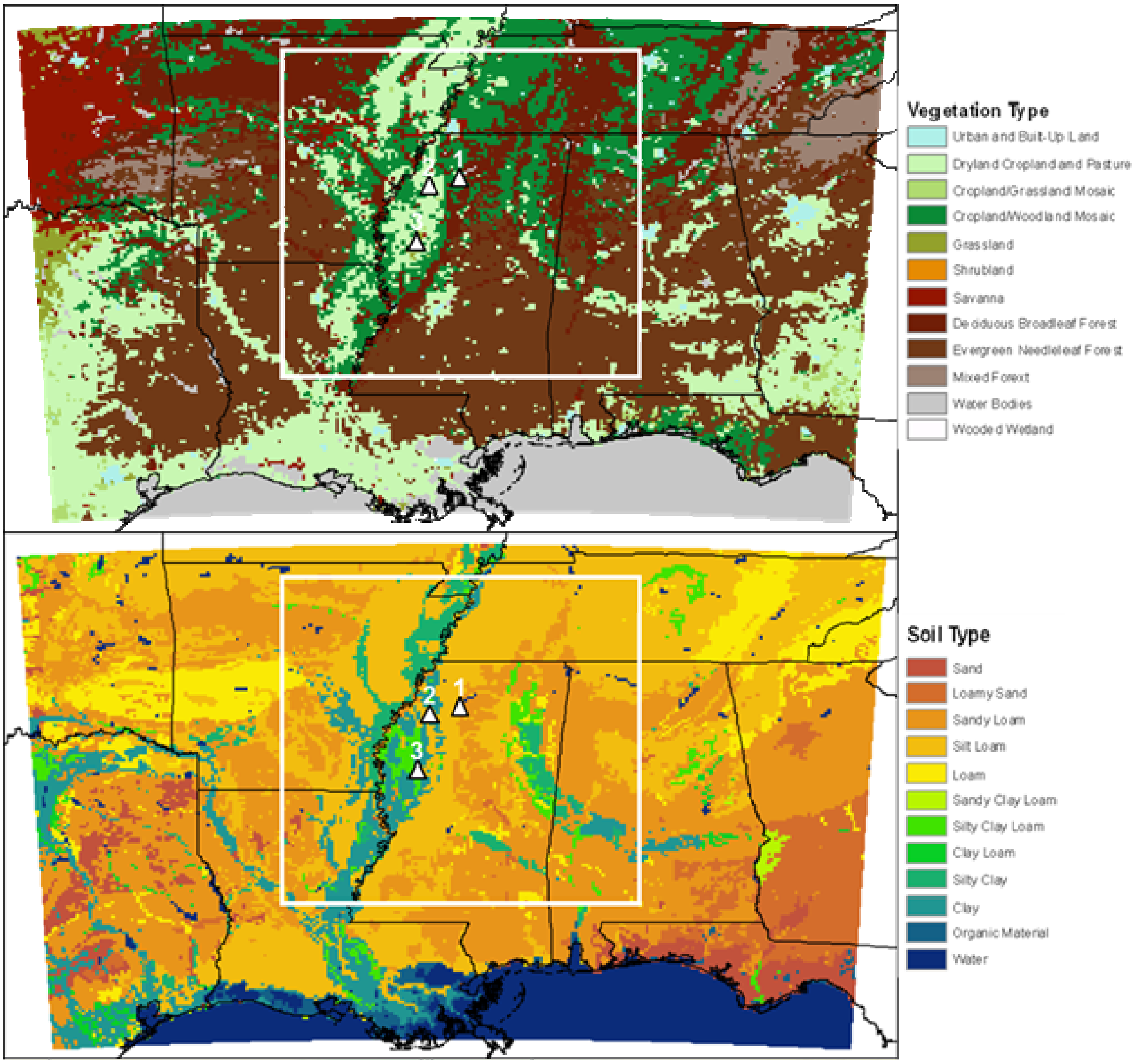

Figure 1. Vegetation and soil type over the southeast US derived from USGS 1-km spatial fields. The white box denotes the extent of the 3-km WRF domain used for analysis. The white triangles denote SCAN sites used for verification, with station labels as follows: 1 – Goodwin Creek Timber, 2 – Vance, and 3 – Beasley Lake.

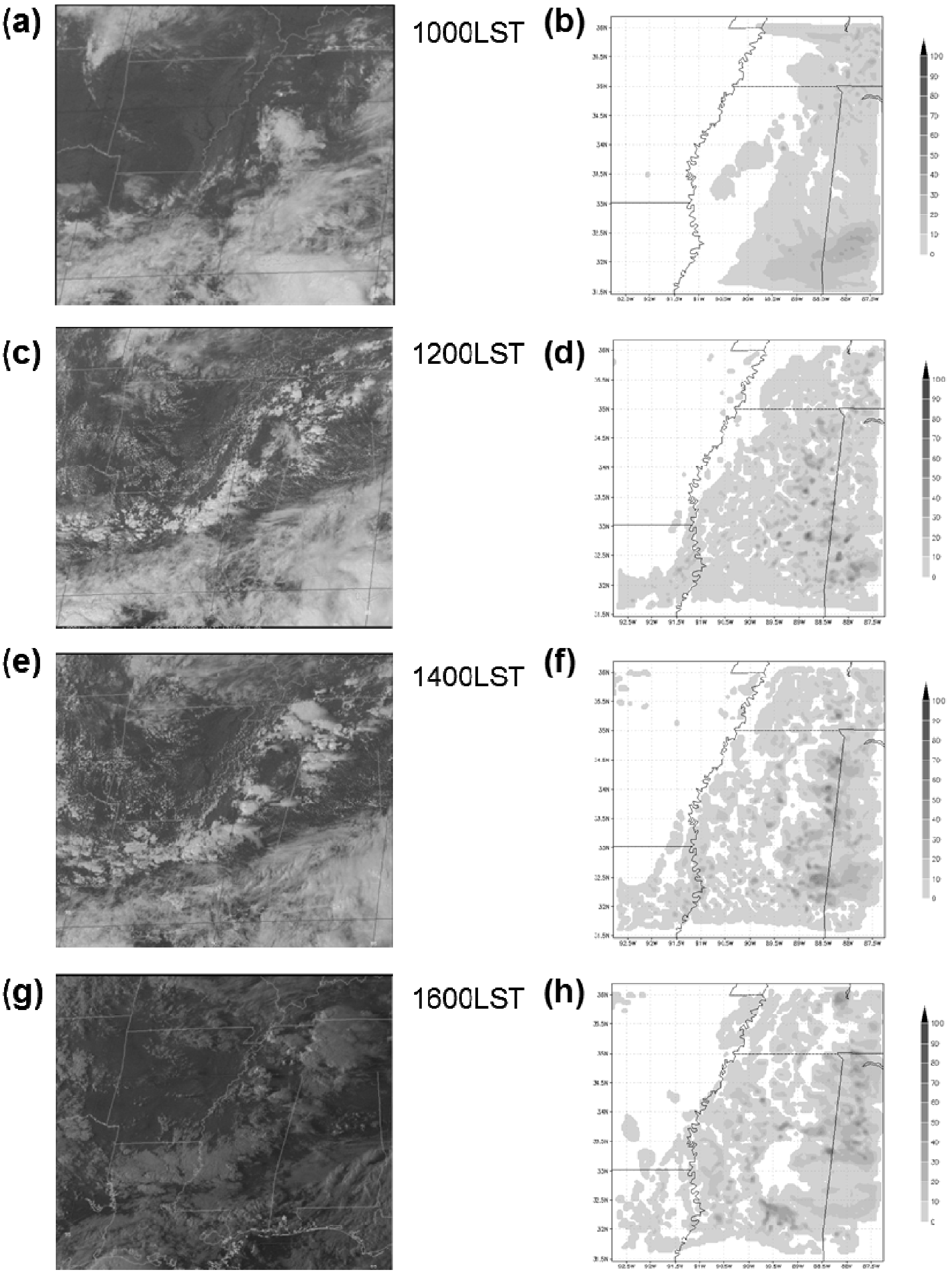

Figure 2. GOES visible imagery and WRF simulated cloud cover (%) at 1000 LST (panels a-b, respectively), 1200 LST (panels c-d, respectively), 1400 LST (panels e-f, respectively), and 1600 LST (panels g-h, respectively).

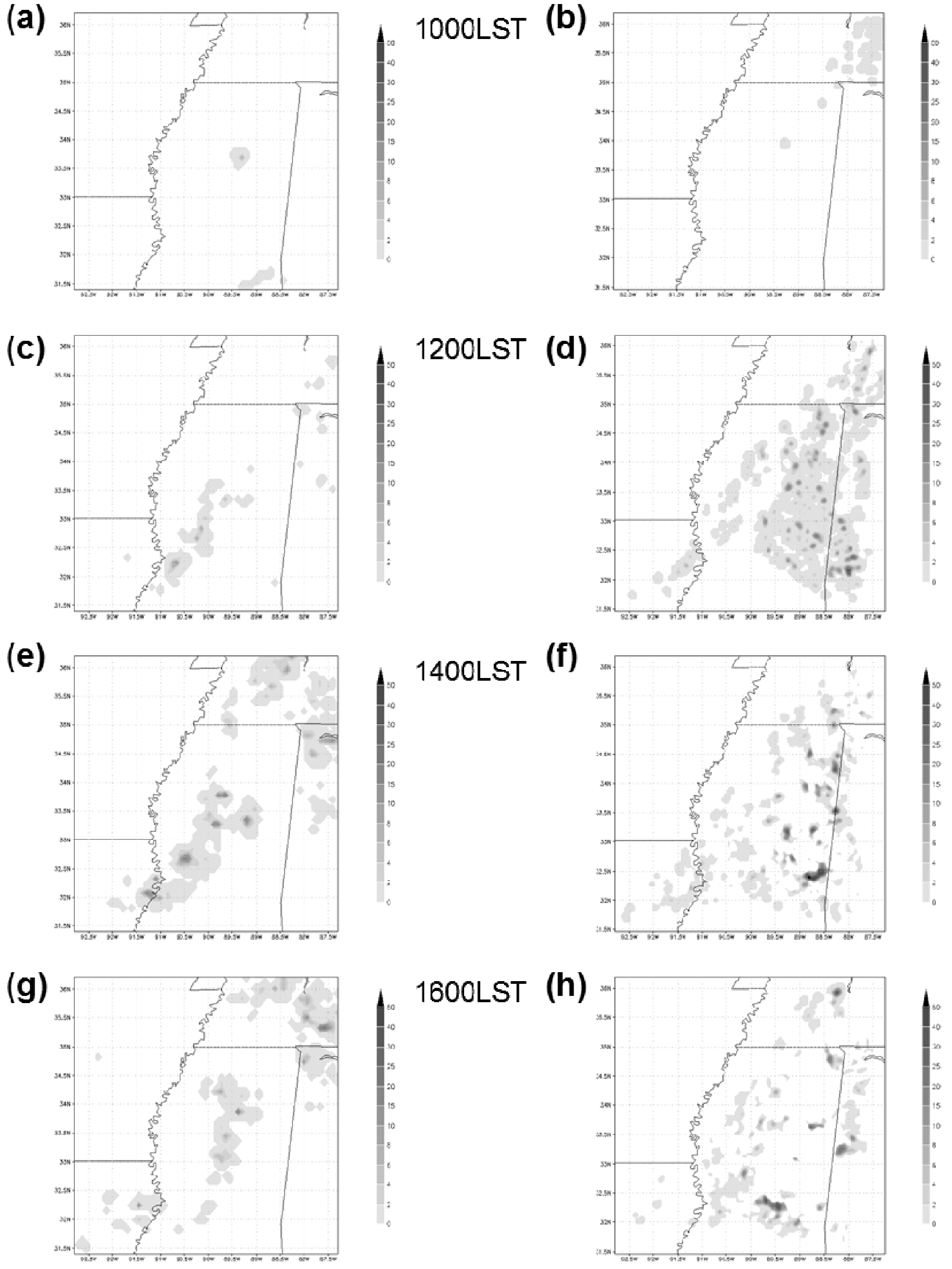

Figure 3. Multi-sensor estimates and WRF simulated values of precipitation (mm) at 1000 LST (panels a-b, respectively), 1200 LST (panels c-d, respectively), 1400 LST (panels e-f, respectively), and 1600 LST (panels g-h, respectively).

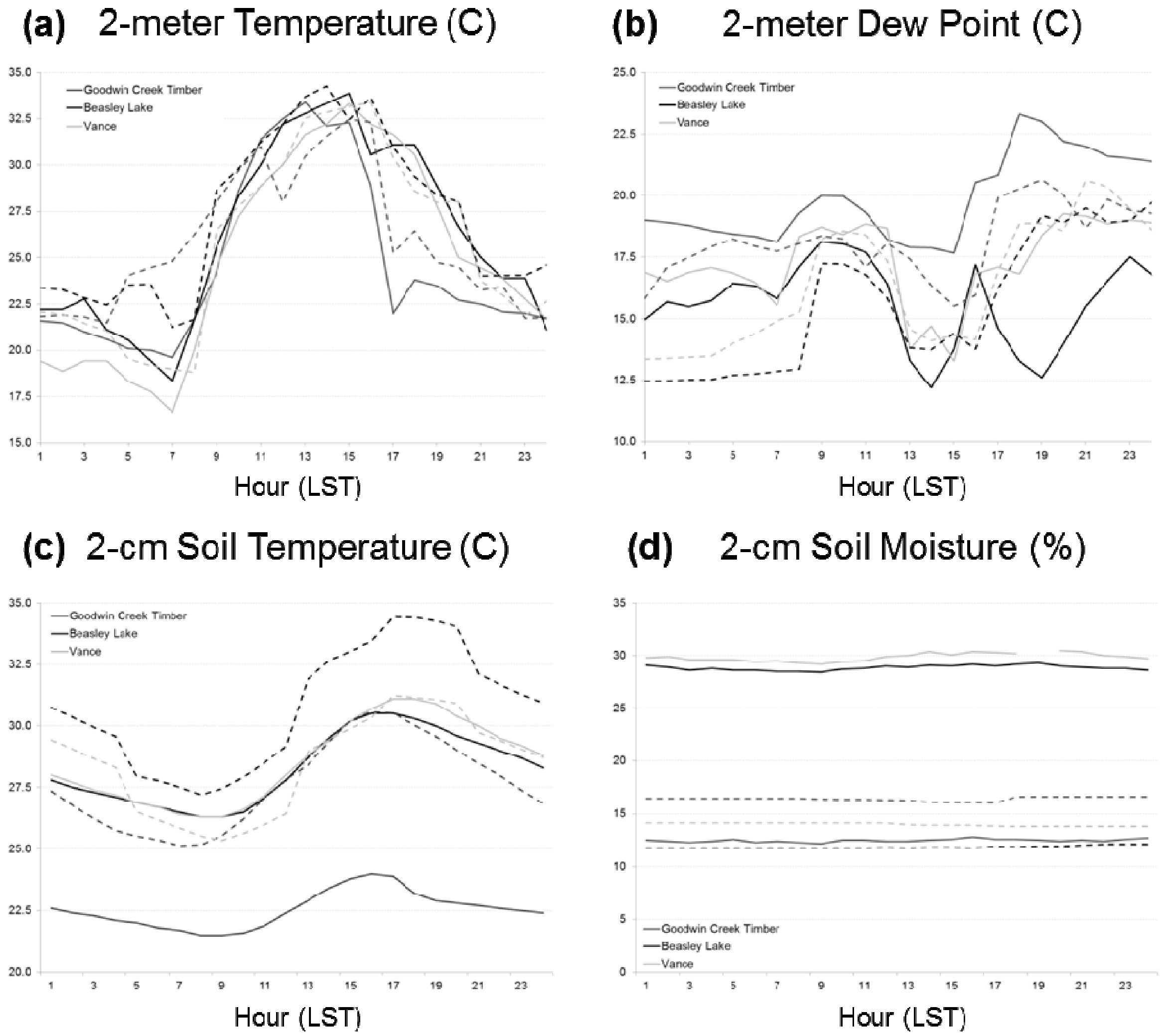

Figure 4. WRF simulated (dashed line) and observations from the SCAN network (solid lines) for (a) 2-meter temperature, (b) 2-meter dewpoint, (c) soil temperature at 2-cm depth (2-10 cm average for simulated values), and (d) soil moisture at 2-cm depth (2-10 cm average for simulated values).

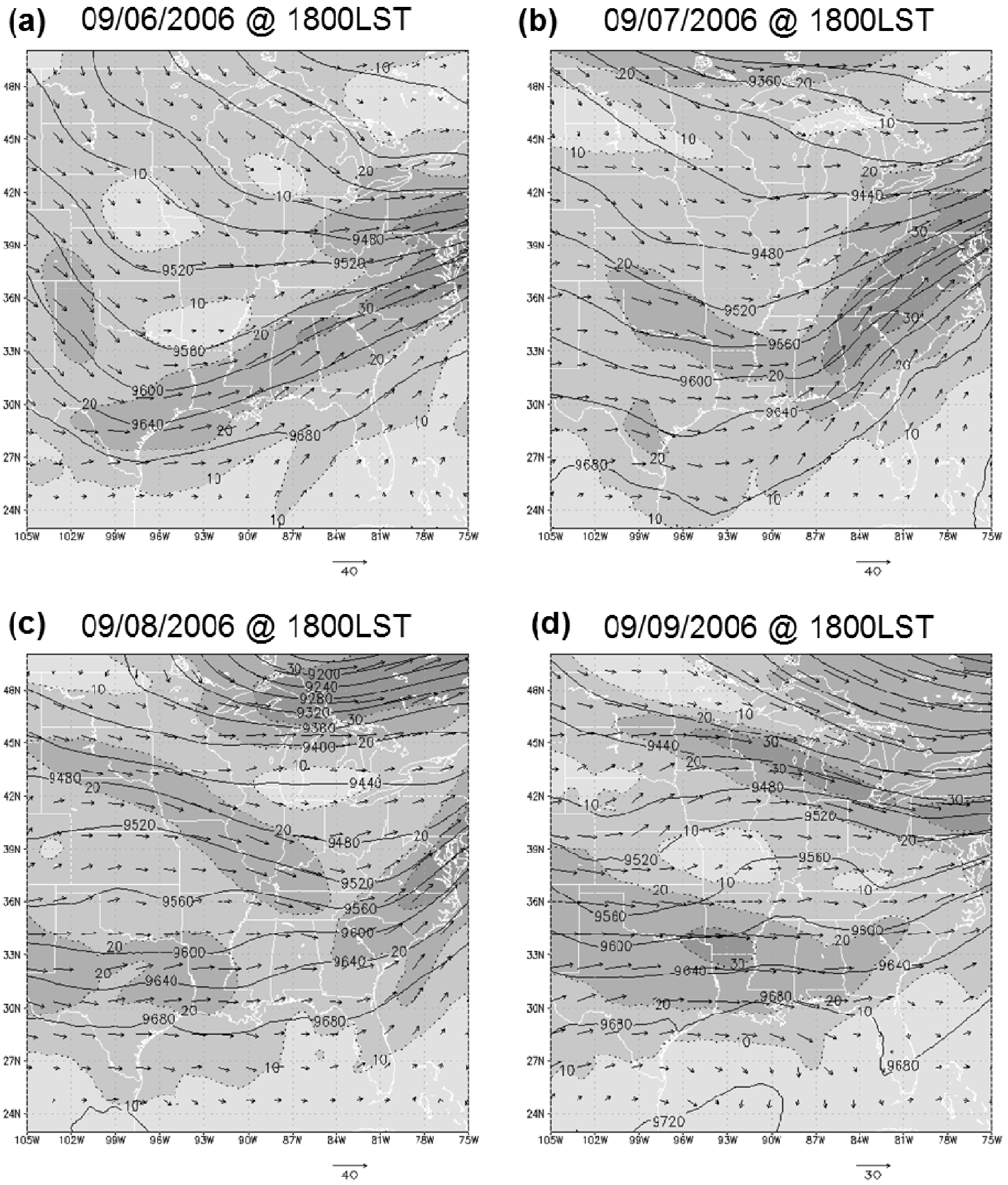

Figure 5. 300 hPa heights (gpm; solid lines), wind magnitude (m/s; dotted lines and shading) and wind vectors at 1800Z on Sept. 6 – 9, 2006 (panels a – d, respectively).

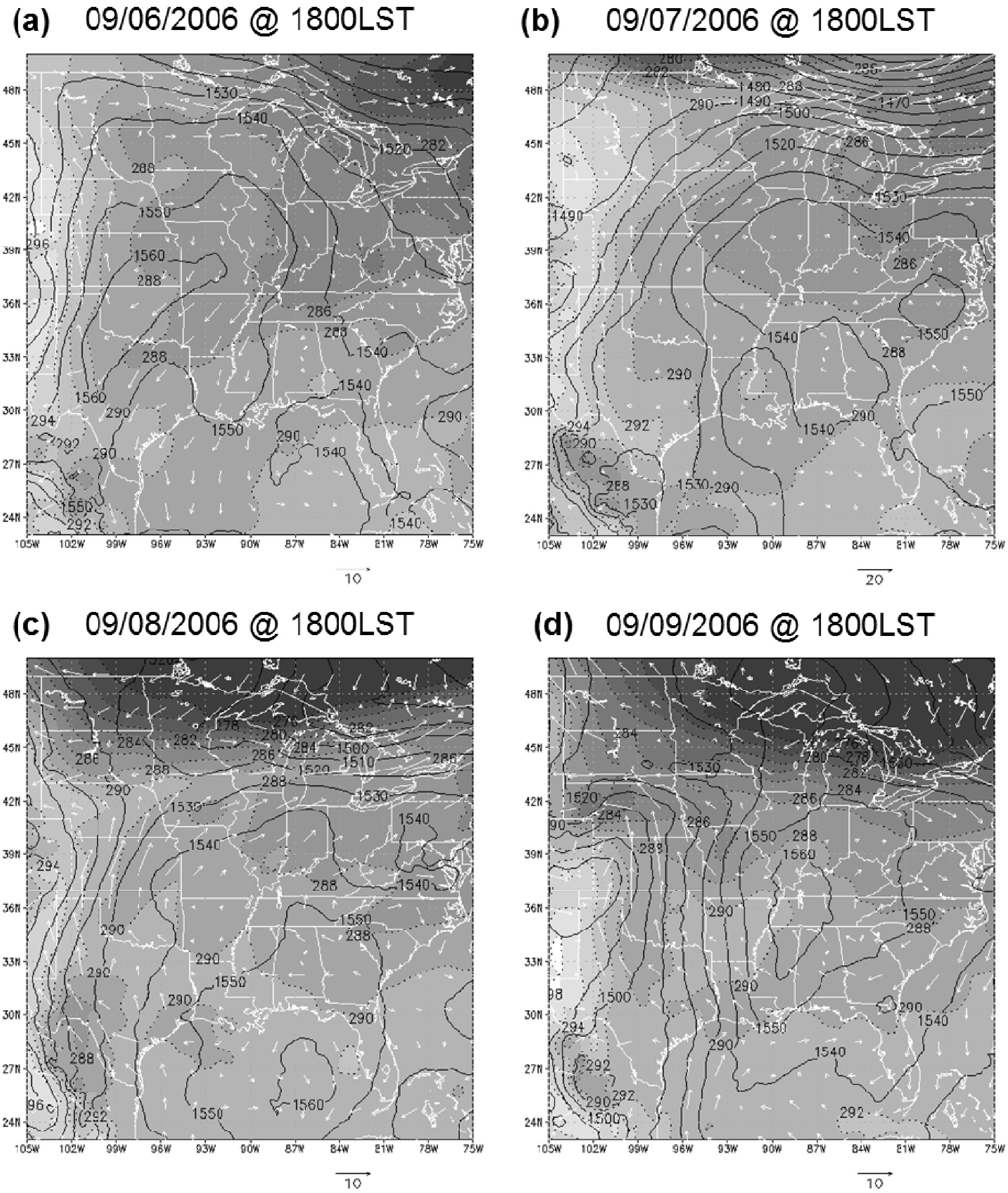

Figure 6. 850 hPa heights (gpm; solid lines), temperature (K; dotted lines and shading), and wind vectors for 1800Z on Sept. 6 – 9, 2006 (panels a – d, respectively).

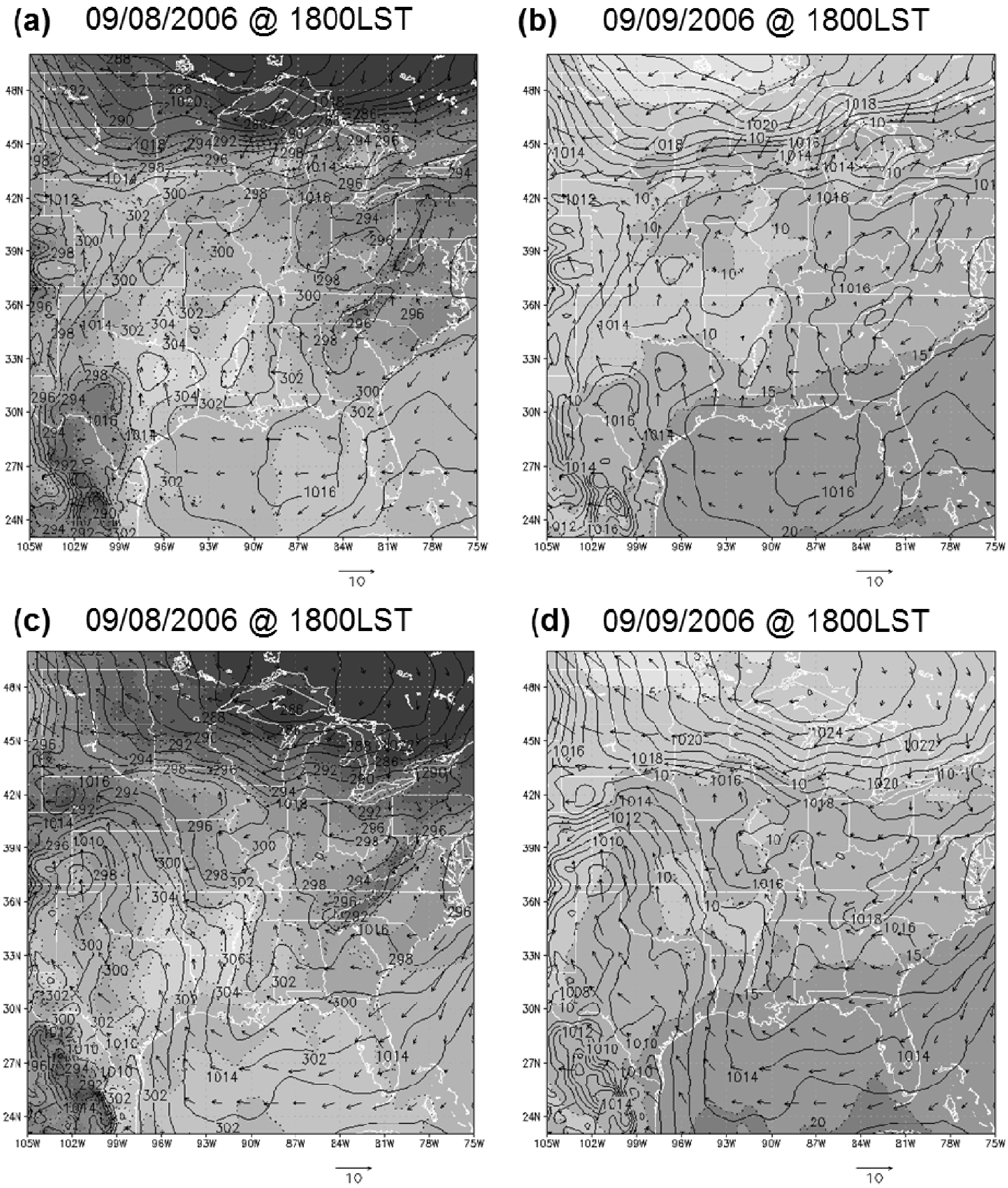

Figure 7. Mean sea level pressure (hPa; solid lines), wind vectors (m/s), and temperature (K; dotted lines and shading) [a,c] or specific humidity (g/kg; dotted lines and shading) [b,d] for Sept. 8-9, 2006 at 1800Z.

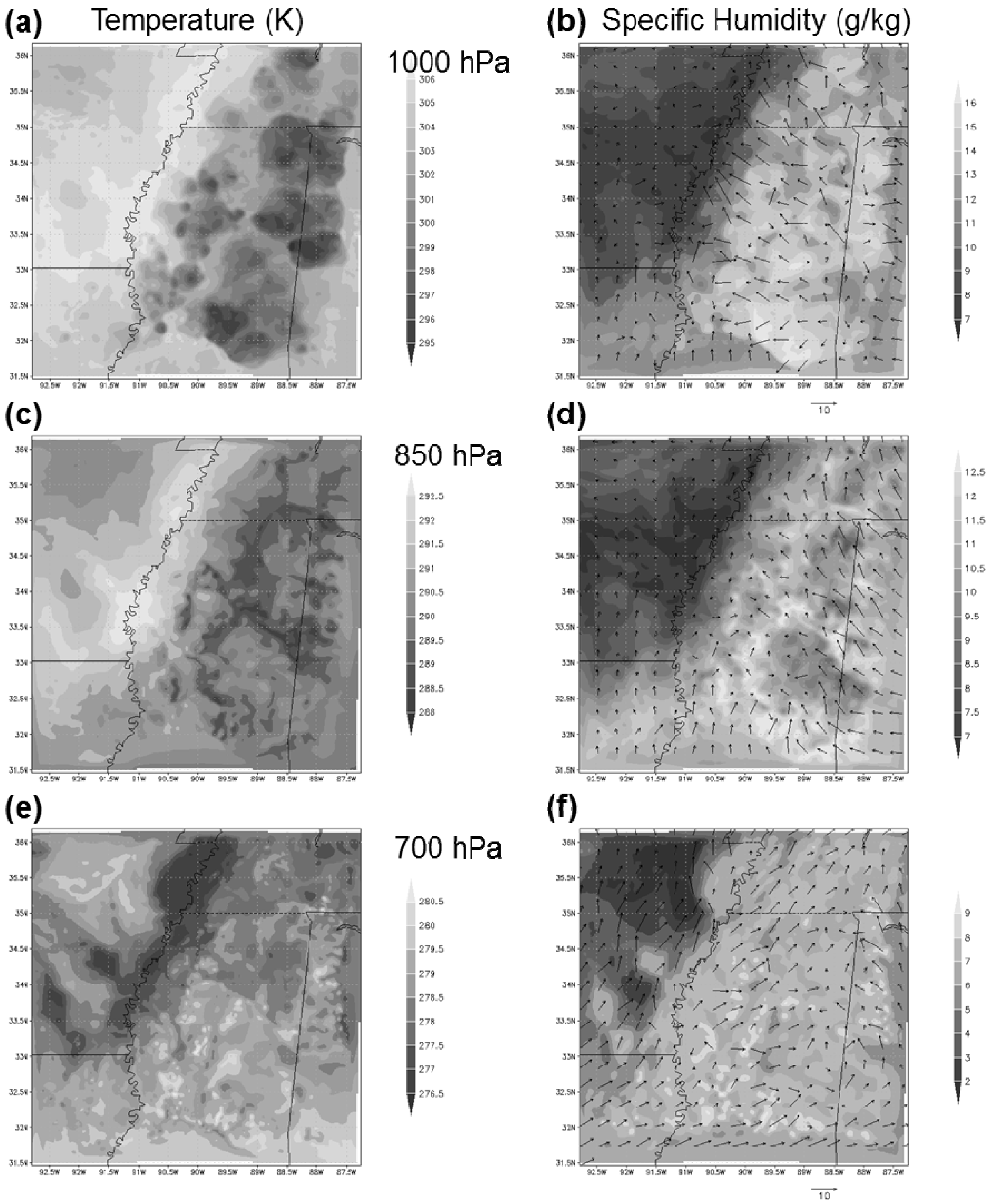

Figure 8. Temperature (K) and specific humidity (g/kg) over the study area for Sept. 9, 2006 at 1400 LST at 1000-hPa (a-b, respectively), 850-hPa (c-d, respectively), and 700-hPa (e-f, respectively).

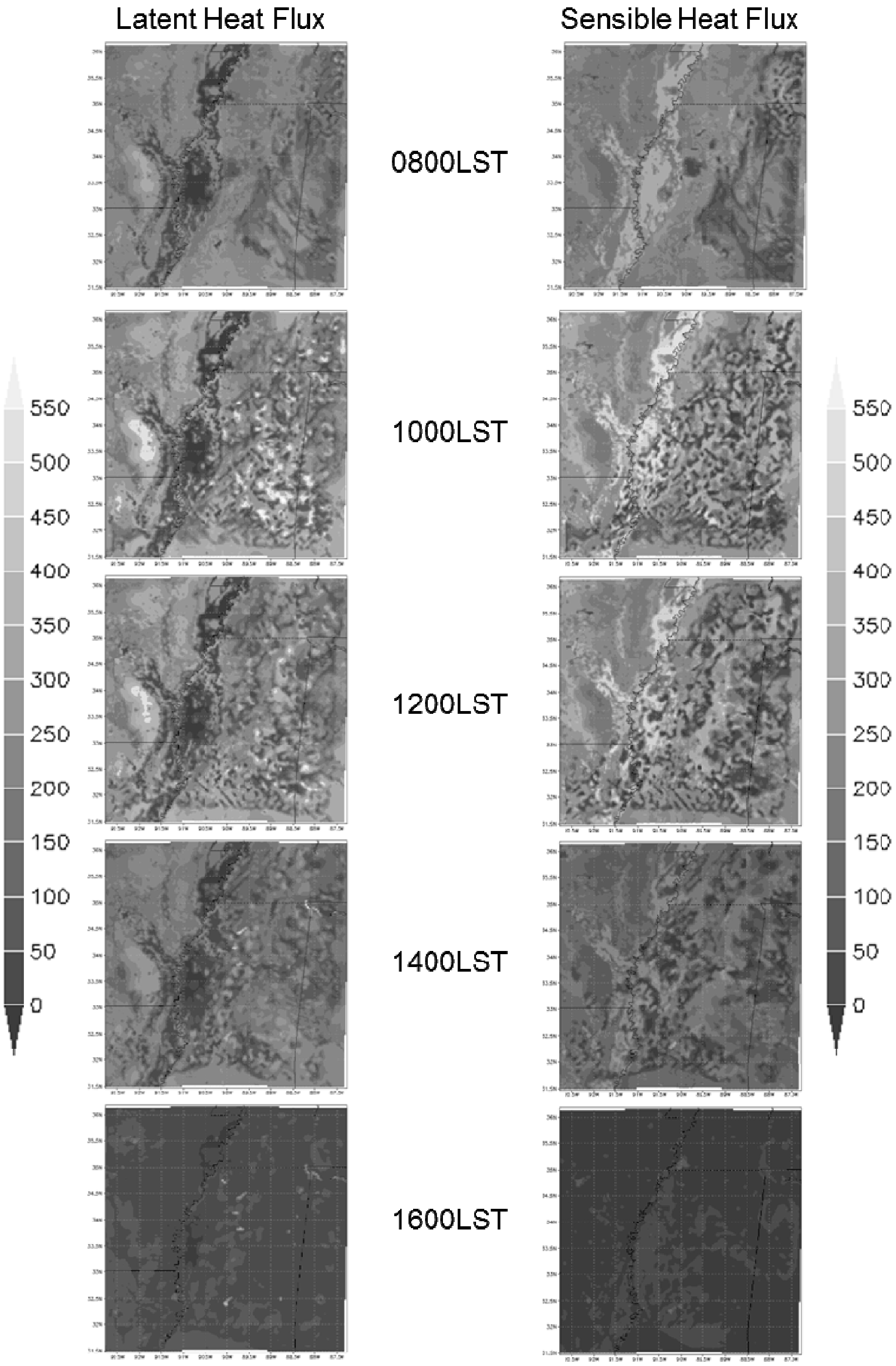

Figure 9. WRF simulated surface sensible and latent fluxes (W/m^2) for 09/09/2006 at 0800 LST (panels a-b, respectively), 1000 LST (panels c-d, respectively), 1200 LST (panels e-f, respectively), and 1400 LST (panels g-h, respectively).

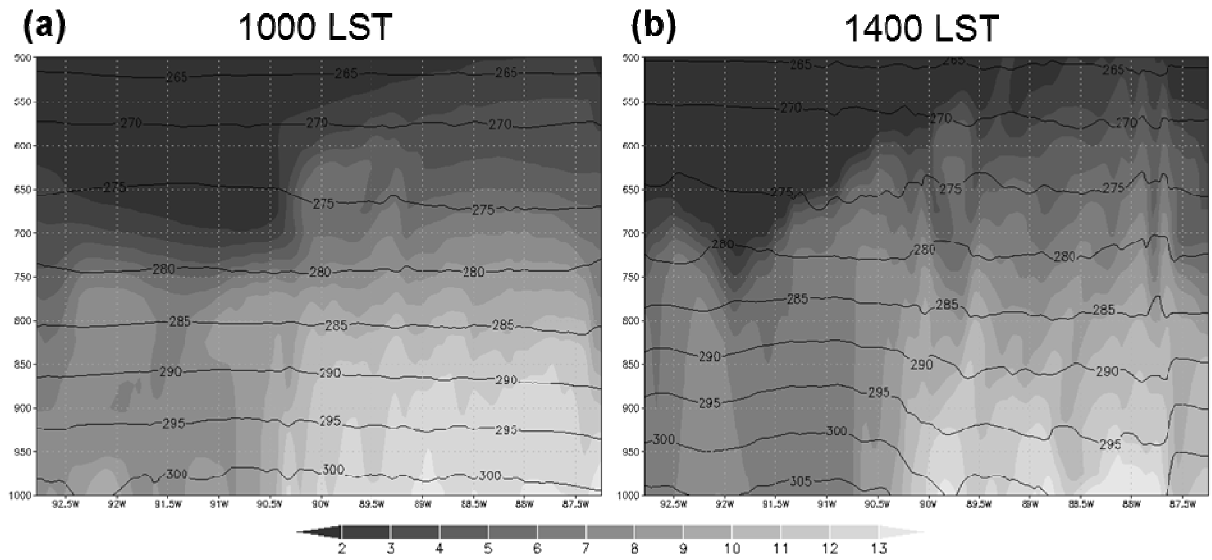

Figure 10. Cross section at 34°N latitude showing specific humidity (g/kg; shaded) and temperature (K; contours) for (a) 1000 LST and (b) 1400 LST.

5. Significant Findings

This project has identified and described the influences of land cover properties, including soil and vegetation conditions, on atmospheric processes over the Mississippi Delta. Specifically, it was found that variations in the energy and moisture fluxes during the warm season along the eastern boundary of the Mississippi Delta were responsible for the generation of a mesoscale convective boundary through processes similar to that found in an urban heat island. This is a direct indication of regional climate change resulting from agricultural practices and the associated anthropogenic modification of the land surface.

Additionally, the development of a convective circulation in the area was responsible for the generation of localized precipitation to the east of the Mississippi Delta. As convection was initiated along the boundary of the land cover discontinuity, prevailing westerly flow caused the cloud cover to advect to the east where the rainfall eventually fell. Under these conditions, it can be said that the atmosphere is acting as a source of interbasin water transport, although the exact volume of moisture removed from the study region has yet to be quantified.

6. Future Research

Based on the findings from this project, future research ideas include quantification of the volume of moisture potentially being transported through atmospheric pathways due to the surface-influenced convective circulation. This would aid in the development and understanding of the sources and releases of moisture over the Mississippi Delta, which could help in local water resource management.

Additionally, using the precipitation patterns outlined through this and previous projects, along with groundwater information from sources such as the Mississippi Department of Environmental Quality and various regional water management districts, a more accurate determination of inputs into the local aquifers can be determined.

Finally, additional research into the variability of the intensity and location of the surface-influenced convective circulation over the Mississippi Delta can be conducted. This would include a sensitivity analysis using the WRF model such that surface and atmospheric conditions could be varied to define the necessary conditions for the circulation to develop. This could help weather and hydrologic forecasters determine when and where the rainfall patterns will be modified due to surface conditions, allowing for a more precise determination of surface precipitation distribution.

7. Information Transfer and Dissemination

The results of the research conducted during the course of this project have been disseminated through peer-reviewed publications and conference presentations. The major results from the project are included in a manuscript that is currently under review in the *Journal of Hydrometeorology*. Additionally, findings were presented at the 2010 Mississippi Water Resources Conference in Bay St. Louis, Mississippi.

8. Student Training

A portion of the research associated with this project was done by Mark Baldwin, a Ph.D. student in the Department of Geosciences at MSU. Although his current research is not directly associated with surface-atmosphere interactions over the Mississippi Delta, he is conducting research related to precipitation prediction and lightning occurrence in the southeast US. Experience while working on this project has helped Mr. Baldwin in the development of the objectives and methodology for his dissertation, and will potentially aid in the development of rainfall prediction and quantification methods over data sparse regions.

9. Financial Summary

Initial budget for funded project:

Cost Category		Percent Time Devoted to Project	Total Salary	Federal Contribution	State Contribution	Matching Contribution	Total
1. Salaries and Wages	PI	15%	$51,665	$3,500	$4,250	$0	$7,750
	GRA	50%	$12,000	$3,000	$3,000	$0	$6,000
	Total			$6,500	$7,250	$0	$13,750
2. Fringe Benefits				$2,048	$2,289	$0	$4,337
3. Materials and Supplies				$100	$200	$0	$300
4. Permanent Equipment				$479	$1,000	$0	$1,479
5. Travel				$987	$1,510	$0	$2,497
6. Other Direct Costs				$990	$1,512	$0	$2,502
Total Direct Costs				$11,104	$13,761	$0	$24,865
8. Indirect Costs				$0	$0	$9,273	$9,273
9. Total Estimated Costs				$11,104	$13,761	$9,273	$34,138

Expenditures during quarterly reporting periods:

1st quarter [3/1/2009 – 6/30/2009]:
Federal:_$3,000.00_, Non-Federal:_$3,701.97_, Cost Share: _$0.00_

2nd quarter [7/1/2009 – 9/30/2009]:
Federal:_$5,765.00_, Non-Federal:_$7,242.00_, Cost Share: _$0.00_

3rd quarter [10/1/2009 – 12/31/2009]:
Federal:_$616.65_, Non-Federal:_$274.75_, Cost Share: _$0.00_

4th quarter [1/1/2010 – 2/28/2010]:
Federal:_$1,700.63_,Non-Federal:_$1,500_, Cost Share: _$9,273.00_

A request for an extension was submitted and approved, leading to expenditures through 11/30/2010 as follows:

Federal:_$21.72__,Non-Federal:_$1,042.28_, Cost Share: _$0.00_

Water quality and other ecosystem services performed in wetlands managed for waterfowl in Mississippi

Basic Information

Title:	Water quality and other ecosystem services performed in wetlands managed for waterfowl in Mississippi
Project Number:	2009MS86B
Start Date:	3/1/2009
End Date:	7/31/2010
Funding Source:	104B
Congressional District:	3rd
Research Category:	Biological Sciences
Focus Category:	Wetlands, Ecology, Water Quality
Descriptors:	None
Principal Investigators:	Richard Kaminski, Amy B. Spencer

Publications

1. Quarterly reports 2009-2010 submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Spencer, A.B. and R.M. Kaminski, Preliminary assessment of ecosystem services provided by moist-soil wetlands, a poster presented at the 2009 Mississippi Water Resources Conference, Tunica, MS, August 5-7, 2009, in Proceedings, p. 31. http://www.wrri.msstate.edu/pdf/2009_wrri_proceedings.pdf
3. Spencer, A.B., H.M. Hagy, and R.M. Kaminski, Crayfish-harvest potential in natural wetlands managed for waterfowl in Mississippi, a poster presented at the 5th North American Duck Symposium, Toronto, Ontario, Canada, August 17-21, 2009.
4. Spencer, A.B., H.M. Hagy, and R.M. Kaminski, Crayfish-harvest potential in wetlands managed for waterfowl in Mississippi, a poster presentation at the 139th meeting of the American Fisheries Society, Nashville, TN. August 31-September 3, 2009.
5. Spencer, A.B. and R.M. Kaminski, Crayfish-harvest potential in moist-soil wetlands, status report presented to the Mississippi Water Resources Research Institute Advisory Board, Mississippi State, MS, November 17, 2009.
6. Spencer, A.B. and R.M. Kaminski, Crayfish-harvest potential in moist-soil wetlands presented to the Delta Wings Hunt Club, Batesville, MS, November 20, 2009.
7. Spencer, A.B., and R.M. Kaminski, 2010, Water quality and other ecosystem services from wetlands managed for waterfowl in Mississippi, final technical report submitted, Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 11 pgs.

Project Title: Water quality and other ecosystem services from wetlands managed for waterfowl in Mississippi

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Focus Categories: WL, ECL, WQL,

Keywords: aquatic invertebrates, crayfish, ecosystems, sedimentation, water quality, watershed management, wetlands

Federal Funds Spent: $11,555

Cost-Share Funds Spent: $23,763

Technical Abstract

A successful and increasingly applied conservation practice in the Lower Mississippi Alluvial Valley (MAV) to mitigate loss of wetland wildlife habitat and improve water quality has been development and management of "moist-soil wetlands." Whereas a primary goal of moist-soil management is to provide abundant food resources for waterfowl and other waterbirds in the MAV and elsewhere on the wintering and migrational grounds, this conservation practice has the potential to provide ecosystem services critical to restoring ecosystem functions in the MAV. Within the MAV, strategic location of natural moist-soil wetlands amid farmed lands can reduce dispersal of sediments and other nutrients into surrounding watersheds. Moreover, a significant potential exists for native crayfish (*Procambarus* spp.) harvest in moist-soil wetlands in the MAV. Our current research is designed to quantify nutrient management and crayfish harvest as ecosystem services provided by moist-soil wetland management in the MAV. During spring 2009, we estimated baseline water quality parameters and average daily yield of crayfish from 9 moist-soil wetlands in Mississippi. Mean NO_3-N, NH_4-N, and PO_4-P concentrations were variable whereas total suspended solid concentrations decreased over time. Average daily yield of crayfish was 1.75 kg ha^{-1} (CV = 16%, n = 9). We continued our study in spring-summer 2010 in wetlands in Arkansas, Louisiana, and Mississippi. Preliminary estimates of average daily yield of crayfish in 2010 was 2.18 kg ha^{-1} (CV = 30%, n = 15). In July 2010, we installed water quality monitoring stations at 6 wetlands and 6 agriculture fields. We will use the data from these stations to estimate and compare monthly loads (kg ha^{-1}) of nutrients and solids from moist-soil wetlands and flooded agricultural fields. Quantifying these ancillary ecosystem services of moist-soil wetlands will encourage further establishment and management of these wetlands in the MAV and elsewhere for wildlife and associated environmental benefits.

INTRODUCTION

Loss of wetlands in the MAV has reduced surface water quality (e.g., Mitsch et al. 2005, Shields et al. 2009). To address loss of ecosystem services, ecologists and wildlife managers have encouraged best management practices (Maul and Cooper 2000, Stafford et al. 2006, Manley et al. 2009) and reestablishment of wetlands (Mitsch et al 2005, Kovacic et al. 2006, Kross et al. 2008) throughout the Mississippi River drainage. A successful management practice in the MAV to address loss of wetland wildlife habitat has been the establishment of moist-soil wetlands. Moist-soil wetlands are naturally vegetated basins, usually by herbaceous annuals (e.g., grasses, sedges), that are prolific producers of seeds and tubers. Because moist-soil wetlands can provide 4-10 times the carrying capacity of harvested agriculture fields in MAV (Kross et al. 2008), management of these habitats is encouraged to meet the goal of sustaining continental populations of waterfowl under the North American Waterfowl Management Plan (United States Fish and Wildlife Service 1986).

Additionally, within the MAV, strategic location of moist-soil wetlands amid farmed landscapes can reduce dispersal of sediments and other nutrients into surrounding watersheds. Predictions have been made regarding the environmental significance of this conservation practice relative to improving surface water quality in the MAV (Mitsch et al. 2005, Murray et al. 2009). However, to our knowledge, no effort has been made to quantify the success of this conservation practice to meet the goals of federal environmental quality mandates such as the Clean Water Act (CWA).

In addition to benefits provided by living plant material in moist-soil wetlands (e.g., carbon sequestration), seasonal flooding promotes decomposition of senescent vegetation (Magee 1993). Crayfish feed on the microbial consumers of detritus and other macroinvertebrates found in wetlands (Alcorlo et al. 2004). Thus, creating and managing moist-soil wetlands have propensity to provide significant habitat and forage for crayfish, opportunities for crayfish production and harvest, and additional economic gain for landowners (McClain et al. 1998). Harvest of crayfish for human consumption is significant, amounting to $115 million annually in the southern United States (Romaire et al. 2004). However, traditional crayfish-harvest operations incur considerable costs. Crayfish must be stocked annually into rice or other impounded fields. A sustainable crayfish-harvest from naturally occurring populations in moist-soil wetlands is a likely a cost-effective alternative.

OBJECTIVES

Our project is designed to identify additional ecosystem services provided by public- and private-sector management of naturally and artificially flooded moist-soil wetlands in the Mississippi Alluvial Valley (MAV). Specifically, the first year of our study was designed to (1) provide a baseline for water quality benefits accrued by retaining winter and spring waters in managed wetlands and (2) estimate production of crayfish populations in moist-soil wetlands. We completed the first year of our field research during March-June 2009. We will expand on our efforts during March-June 2010.

METHODS

Study Sites

During the 2009 field season, we identified 9 moist-soil wetlands on public and private lands in Mississippi. Locations of moist-soil wetlands were: Yazoo National Wildlife Refuge, Hollandale, Mississippi; Panther Swamp National Wildlife Refuge, Yazoo City, Mississippi; Morgan Brake National Wildlife Refuge, Tchula, Mississippi; Coldwater National Wildlife Refuge, Charleston, Mississippi; York Woods, Charleston, Mississippi; Noxubee National Wildlife Refuge, Brooksville, Mississippi; Trim Cane Wildlife Management Area, Starkville, Mississippi; and Property of Mr. C. Clark Young, West Point, Mississippi. During the 2010 field season, we identified 15 moist-soil wetlands on public and private lands in Arkansas, Mississippi, and Louisiana. Locations of the wetlands were: Cache River National Wildlife Refuge, Brinkley, Arkansas; Wappanocca National Wildlife Refuge, Turrell, Arkansas; Coldwater National Wildlife Refuge, Charleston, Mississippi; Property of Dr. Ronal Roberson, Tippo, Mississippi; Morgan Brake National Wildlife Refuge, Tchula, Mississippi; Panther Swamp National Wildlife Refuge, Yazoo City, Mississippi; Yazoo National Wildlife Refuge, Hollandale, Mississippi, Noxubee National Wildlife Refuge, Brooksville, Mississippi; the Property of Mr. C. Clark Young, West Point, Mississippi; Tensas National Wildlife Refuge, Tallulah, Louisiana; Catahoula National Wildlife Refuge, Jena, Louisiana; and Grand Cote National Wildlife Refuge, Marksville, Louisiana. Managed moist-soil wetlands vary in area (1-8 ha), are often fallowed cropland or idled ponds, and have functioning water control structures and levees.

Field and Analytical Methods

We monitored NO_3-N, NH_4-N, PO_4-P and total suspended solid (TSS) concentrations (mg l^{-1}) within each wetland from April to June 2009. Grab samples were taken from each wetland, stored on ice, and transported to the lab. Within 24 hours of sampling, we estimated nutrient concentrations in each sample colorimetrically with a LaMotte handheld colorimeter. We estimated TSS concentrations by filtering a known volume of sample through a pre-washed and dried 1.5-µm glass fiber filter. We then dried the sample-washed filter to a constant weight at 120 C. The difference in weight between the clean filter and the sample-washed filter was used to estimate the concentration of suspended solids in the sample.

The amount of vegetation is thought to have an effect on the yield of crayfish in traditional rice-crayfish production systems (McClain 1997). We evaluated change in mean biomass of vegetation over time by collecting monthly vegetation samples (live and senescent) from ten 0.5-m^2 plots within each wetland. Samples were washed, dried at 60 C and weighed (g) to estimate dry vegetative mass.

We estimated yield of crayfish in moist-soil wetlands from April to June 2009 and April to June 2010. We set baited pyramid-style crayfish traps at a density of 25 traps ha^{-1}. We were limited by the number of traps and therefore, we set traps in each wetland every other week in 2009. Traps were baited and checked for crayfish after 48 hours. With extension of FY2009 funds, we purchased additional traps and were able to trap crayfish every week in 2010. Traps were baited and checked for crayfish after 24 hours. All crayfish in traps were taken back to the lab where individuals were sexed, identified to species, weighed (g), and measured for carapace length (mm). We estimated relative abundance as crayfish $trap^{-1}$ and yield as kg ha^{-1}. We also compared length-frequency distributions of crayfish across moist-soil wetlands with a Kruskal-Wallis test ($\alpha = 0.05$).

RESULTS

The average concentration of TSS across all wetlands was 17.5 mg l^{-1} (CV = 5%). A general decline in TSS concentrations was apparent across the study period (Table 1). The change in TSS concentrations across the study period for individual wetlands ranged from a decline of 84% to an increase in 29% (Table 2). The average concentration of NH_3-N across all wetlands was 0.58 mg l^{-1} (CV = 10%). Concentrations of NH_3-N did not exhibit a change over the study period (Table 1). The average concentration of NO_3-N across all wetlands was 0.07 mg l^{-1} (CV = 66%). Concentrations of NO_3-N were variable and did not exhibit a discernable temporal trend (Table 1). The average concentration of PO_4-P across wetlands was 0.49 mg l^{-1} (CV = 4%). As with NH_3-N, concentrations of PO_4-P did not exhibit a temporal trend (Table 1). Average vegetative biomass in moist-soil wetlands from April to June 2009 was 29.2 g m^{-2} (CV = 27%). Vegetation in some wetlands decreased over time, while others exhibited increases in vegetation (Table 3).

We harvested a total of 91 kg of crayfish from 1,298 trap sets in 2009. The pooled mean relative abundance was 2.6 crayfish $trap^{-1}$ (CV = 17%) and the mean daily yield was 1.75 kg ha^{-1} (CV = 16%). Average yield in wetlands in East Mississippi were lower than from wetlands in the Delta region (Figure 1). We encountered two species of crayfish in the sampled moist-soil wetlands: *Procambarus clarkii*, the Red Swamp Crayfish; and *Procambarus acutus*, the White River Crayfish. Both species are the primary species cultured in rice-crayfish production systems. We only encountered the Red Swamp crayfish in wetlands located in the Delta region. The length-frequency distributions of the Red Swamp crayfish were significantly different across wetlands with wetlands in the south Delta region producing larger individuals (K-W $p < 0.0001$; Figure 2). We harvested the White River crayfish from all wetlands except for one wetland in the south Delta region. The length-frequency distributions of the White River crayfish differed significantly across wetlands and wetlands in East Mississippi produced significantly smaller individuals (K-W $p < 0.0001$; Figure 3).

In 2010 we harvested a total of 94 kg of crayfish from 2,005 trap sets in wetlands located in Arkansas, Mississippi, and Louisiana. Preliminary estimates of the pooled mean relative abundance is 2 crayfish $trap^{-1}$ (CV = 16%) and the mean daily yield is 2.18 kg ha^{-1} (CV = 16%). We are currently analyzing harvest data from 2010. Full results will be reported in FY2010 final report.

DISCUSSION

Seasonally flooded plant communities concentrate nutrients and sediments from agricultural and other non-point sources of run-off (Maul and Cooper 2000, Manley et al. 2009). Whereas site-specific investigations of the environmental significance are key to understanding functional capabilities of these wetlands (King et al. 2009), a landscape- or ecosystem-scale (Mitsch and Day 2004) approach is necessary to predict the capability of this practice to improve ecosystem quality. In 2009, we demonstrated that moist-soil wetlands exhibit declines in total suspended solid concentrations during spring while nutrient concentrations did not exhibit discernable reductions over time. Nonetheless, estimates of nutrient concentration from moist-soil wetlands in 2009 were lower than those estimated from agriculture fields in Mississippi (Maul and Cooper 2000). For example, water in flooded agriculture fields exhibit average concentrations of suspended solids of 283 mg l^{-l} (Maul and Cooper 2000). Whereas estimates of concentrations within wetlands provide information regarding within-wetland water quality, current estimates of the benefit of these wetlands to landscape environmental quality are unknown. Therefore, in 2010, we installed water sampling stations at the outflow of six wetlands and six agriculture fields. We will use the data from these stations to estimate and compare monthly loads (kg ha^{-1}) of nutrients and solids from moist-soil wetlands and flooded agricultural fields.

Vegetative biomass decreased in some wetlands whereas it increased in others during spring-summer 2009. Increases in vegetative biomass in these wetlands were caused by growth of submerged and emergent aquatic macrophytes (e.g., *Ludwigia leptocarpa*). Because of predictions made from rice-crayfish production systems, we expected that decreases in vegetative biomass in wetlands would result in lower yields of crayfish. We did not see an apparent relationship in the change in vegetation and crayfish yield (Table 3). We collected vegetation samples from wetlands in 2010. Therefore, a larger sample sizes will enable us to evaluate the relationship between vegetative biomass and crayfish yields in 2011.

In high yield rice-crayfish production systems in Louisiana, producers can expect daily yields of 10.5 kg ha^{-1}. Our yields from 2009 and 2010 were substantially lower in moist-soil wetlands. Whereas yields are greater in traditional production fields, these systems also have greater associated fixed and variable costs compared to moist-soil wetlands (Avery et al. 1998). For example, a producer with a 16-ha rice field can expect to spend $1,000 to $2,000 annually on planting a forage base in fields. Whereas in moist-soil wetlands this variable cost is nonexistent or minimal because the forage base is natural vegetation. Additionally, a crayfish producer in Louisiana must produce high yields to profit. A preliminary estimate of the expected direct costs associated with rice-crayfish operations is \$750 ha^{-1}. Direct costs associated with harvesting crayfish from moist-soil wetlands is likely only to include costs for bait and traps and is estimated to be \$485 ha^{-1}. Therefore, producers of crayfish in rice-crayfish operations must either sell more crayfish or demand higher prices to cover direct costs. We will use estimated yields from 2009 and 2010 to refine our estimates of the economic potential of crayfish harvest from moist-soil wetlands.

Strategic location of moist-soil wetlands amid farmed lands can reduce transport of sediments and other nutrients into surrounding watersheds and thus enhance water and environmental qualities. A major environmental, ecological, and economic consequence of loss of wetlands throughout the Mississippi River Basin has been the development of the hypoxic zone in the Gulf of Mexico (Rabalais et al. 2002). Moist-soil wetlands may reduce nitrogen inputs to the Gulf of Mexico. Subsequently, quantifying ecosystem services provided by moist-soil management will facilitate fulfillment of proposed surface water quality regulations (i.e., total maximum daily loads). Finally, understanding the economic benefits of crayfish harvests from moist-soil wetlands will likely encourage the establishment of these wetlands and therefore increase habitat for waterfowl and other wetland wildlife throughout the MAV.

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PUBLICATIONS AND PRESENTATIONS

Spencer, A. B. and R. M. Kaminski. 2009. Preliminary assessment of ecosystem services provided by moist-soil wetlands. Poster. Presented at the Mississippi Water Resources Conference, Tunica, MS. August 5-7, 2009.

Spencer, A.B., H.M. Hagy, R.M. Kaminski. 2009. Crayfish-harvest potential in natural wetlands managed for waterfowl in Mississippi. Poster. Presented at the 5th North American Duck Symposium, Toronto, Ontario, Canada, August 17-21, 2009.

Spencer, A.B., H.M. Hagy, R.M. Kaminski. 2009. Crayfish-harvest potential in wetlands managed for waterfowl in Mississippi. Poster Presentation presented at the 139th meeting of the American Fisheries Society, Nashville, TN. August 31-September 3, 2009.

Spencer, A. B., and R. M. Kaminski. 2009. Crayfish-harvest potential in moist-soil wetlands. Mississippi Water Resources Research Institute. Advisory Board Meeting. Starkville, Mississippi. November 17, 2009.

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Spencer, A. B., R. M. Kaminski, L. D'Abramo, and J. Avery. 2010. Crayfish harvest: An ancillary ecosystem service provided by moist-soil management. Oral Presentation. Presented at the International Association of Astacology, Columbia, Missouri, July 18-23, 2010.

TRAINING POTENTIAL

The proposed project provided necessary field work for Amy Spencer, a PhD student in Department of Wildlife and Fisheries at Mississippi State University. Ms. Spencer's field of interest is in wetland ecology and aquatic ecosystem management. She also holds a Master's degree in fisheries from the department and her extensive aquatic ecology and population modeling background will aid in the successful implementation of the proposed research. We hired Christian Singleton, a Starkville High School senior who learned valuable field experience and knowledge about wetland and waterfowl conservation. We also hired Mason Conley, an undergraduate student in the Department of Wildlife, Fisheries, and Aquaculture at Mississippi State University. Numerous graduate students in the Department of Wildlife, Fisheries, and Aquaculture also volunteered invaluable time. We also encouraged landowners and land managers to observe water quality and crayfish sampling activities. We received field assistance from one landowner as well. We also involved high school students in crayfish harvest activities during a College of Forest Resources' sponsored summer camp. We believe that continuing our model of a combination of formal and informal training will increase the population of individuals aware of wetland conservation principles.

Student Training

Name	Level	Major
Amy B. Spencer (Co-PI)	Ph.D.	Forest Resources
Christian Singleton (Wage)	High School	Starkville (MS) High
Mason Conley (Wage)	B.S.	Wildlife and Fisheries
Alan Leach (Volunteer)	M.S.	Wildlife and Fisheries
Matt Palumbo (Volunteer)	M.S.	Wildlife and Fisheries
James Callicutt (Volunteer)	M.S.	Wildlife and Fisheries
Jacob Straub (Volunteer)	Ph.D.	Forest Resources
Justyn Foth (Volunteer)	M.S.	Wildlife and Fisheries
Heath Hagy (Volunteer)	Ph.D.	Forest Resources

Table 1. Average (± S.E.) total suspended solid and nutrient concentrations (mg l^{-1}) in moist-soil wetlands in Mississippi for each sampling event in 2009.

	Period				
Variable	1	2	3	4	5
TSS	20.2±4.73	18.5±4.46	17.7±4.00	16.3±3.60	14.8±3.36
NH_3-N	0.80±0.24	0.55±0.03	0.51±0.05	0.50±0.1	0.52±0.05
NO_3-N	0.03±0.02	0.004±0.003	0.01±0.01	0.24±0.06	0.05±0.02
PO_4-P	0.46±0.05	0.56±0.14	0.49±0.13	0.52±0.13	0.44±0.08

Table 2. Percent change in total suspended solid concentrations in moist-soil wetlands in Mississippi during April to June 2009. ND = North Delta; EMS = East Mississippi; SD = South Delta.

Site	% change in total suspended solids
ND1	-84.3
ND2	-59.6
ND3	-64.2
EMS1	-50.0
EMS2	-34.4
EMS3	+29.49
SD1	-2.6
SD2	-7.7
SD3	-8.2

Table 3. Average (± S.E.) daily yield of crayfish and percent change in vegetative biomass in moist-soil wetlands from April to June 2009.

Site	Average [a] yield (kg/ha)	% change in vegetation dry mass
ND1	1.0 ± 0.4	-35.0
ND2	3.6 ± 0.2	-65.0
ND3	2.1 ± 0.4	+35.0
EMS1	1.1 ± 0.4	-43.9
EMS2	1.2 ± 0.3	+41.6
EMS3	0.9 ± 0.2	+40.1
SD1	2.6 ± 1.2	+82.7
SD2	3.6 ± 1.4	+36.4
SD3	2.2 ± 0.5	+92.2

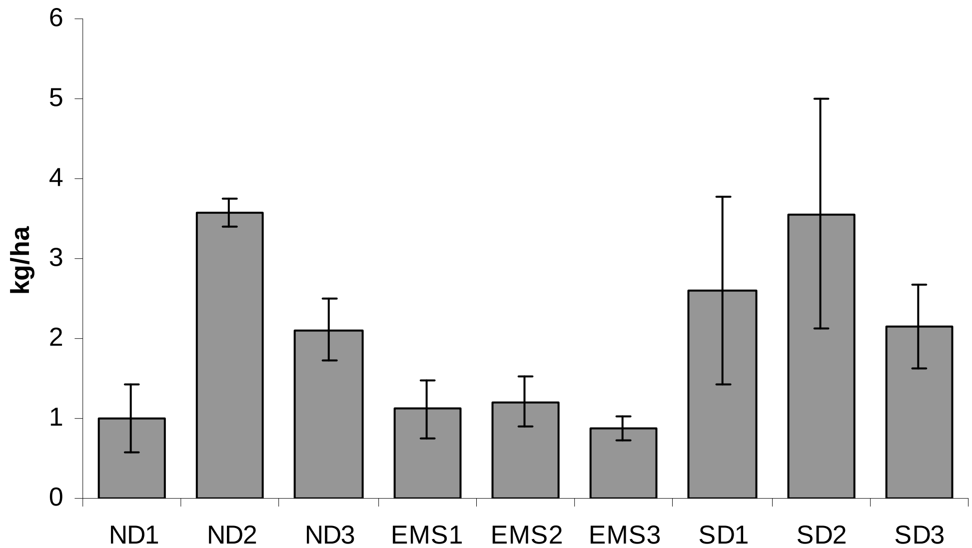

Figure 1. Average daily yield of crayfish from moist-soil wetlands in Mississippi during April to June 2009.

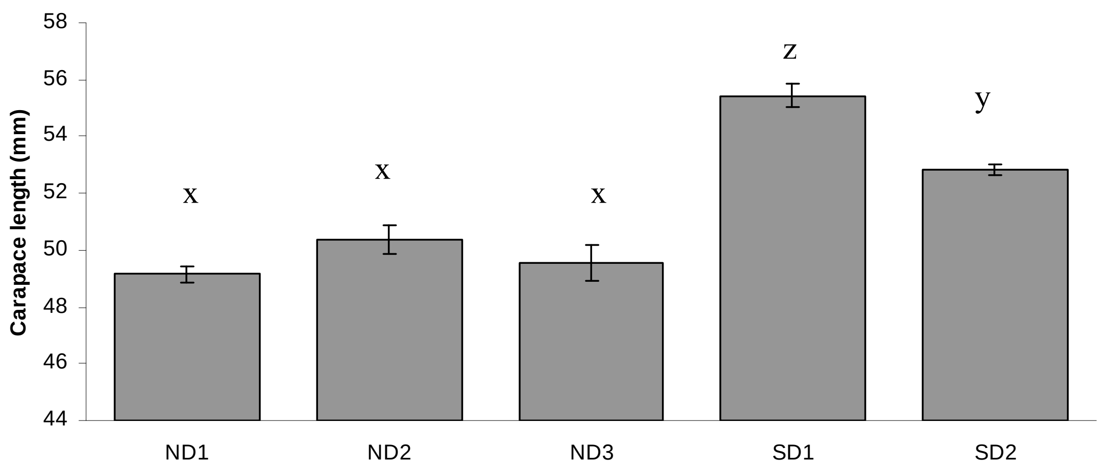

Figure 2. Average carapace length of Red Swamp crayfish harvested from moist-soil wetlands during April to June 2009. Letters designate significant ($p < 0.0001$) least-squared differences in length-frequency distributions.

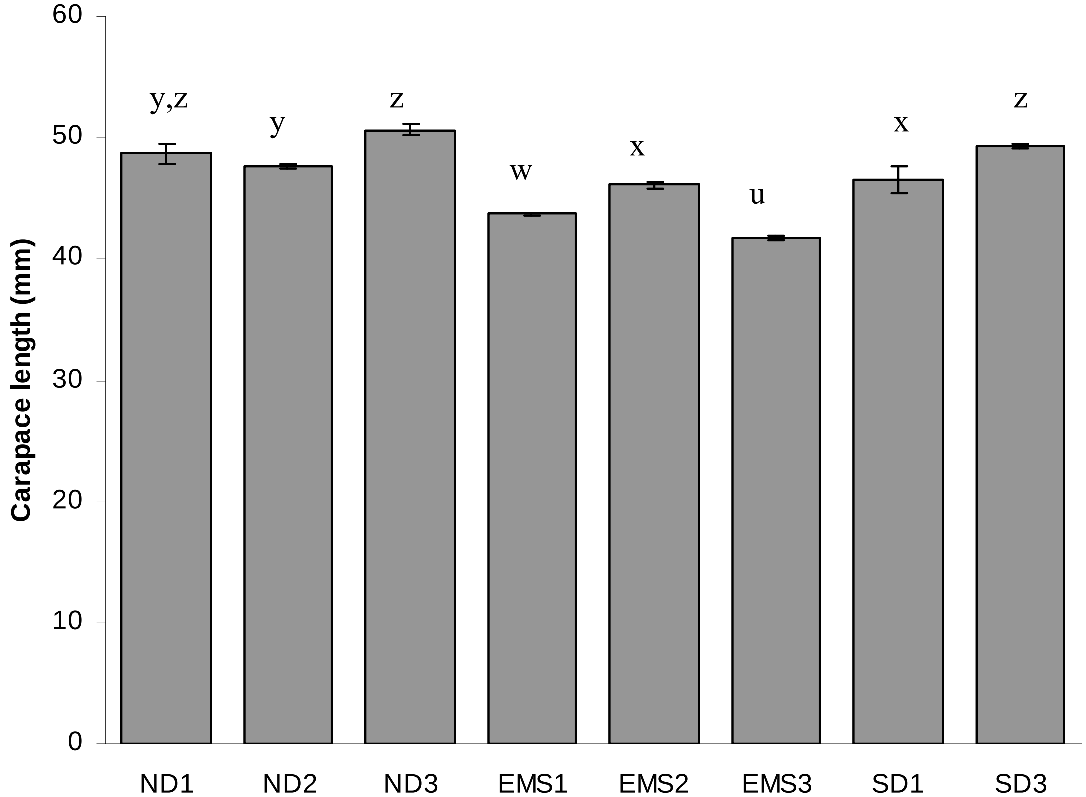

Figure 3. Average carapace length of White River crayfish harvested from moist-soil wetlands during April to June 2009. Letters designate significant ($p < 0.0001$) least-squared differences in length-frequency distributions.

Molecular Identification of Bacterial Communities Associated with Biodegradation of Pentachlorophenol in Groundwater

Basic Information

Title:	Molecular Identification of Bacterial Communities Associated with Biodegradation of Pentachlorophenol in Groundwater
Project Number:	2009MS87B
Start Date:	3/1/2009
End Date:	6/30/2010
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Congressional District:	3rd
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Descriptors:	None
Principal Investigators:	M Lynn Prewitt, Hamid Borazjani, Susan Diehl

Publications

1. Quarterly reports 2009-2010 submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Stokes, C.E., M.L. Prewitt, and H. Borazjani, Molecular Identification of Pentachlorophenol (PCP) Tolerant Bacterial Communities in Contaminated Groundwater, poster presentation at the 2009 Mississippi Water Resources Conference, Tunica, Mississippi, August 5-7, 2009. Proceedings, p. 32, http://www.wrri.msstate.edu/pdf/2009_wrri_proceedings.pdf.
3. Beth Stokes status presentation on Molecular Identification of Pentachlorophenol (PCP) Tolerant Bacterial Communities in Contaminated Groundwater to the Mississippi Water Resources Research Institute Advisory Board, November 17, 2009, Mississippi State, MS.
4. Stokes, C.E., M.L. Prewitt, and H. Borazjani, Molecular Identification of Pentachlorophenol (PCP) Tolerant Bacterial Communities in Contaminated Groundwater Undergoing Air-Sparging Remediation (Abstract), presented at the 106th Annual Meeting of the American Wood Protection Association, May 24, 2010, Savannah, GA, p. 184, http://www.awpa.com/publications/2010ProceedingsToC.pdf.
5. Prewitt, M.L., H. Borazjani, and S.V. Diehl, 2010, Molecular Identification of Bacterial Communities Associated with Biodegradation of Pentachlorophenol in Groundwater, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 17 pgs.

Molecular Identification of Bacterial Communities Associated with Biodegradation of Pentachlorophenol in Groundwater

Final Report

Start Date: 03/01/2009
End Date: 06/30/2010

Dr. M. Lynn Prewitt
Dr. Hamid Borazjani
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09/3/2010

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TABLE OF CONTENTS

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Abstract

Pentachlorophenol (PCP) is a toxic and recalcitrant compound used predominately as a wood preservative to protect wood from decay caused by insects and microorganisms. Past storage, treatment and disposal practices of PCP have resulted in groundwater contamination near wood treating sites in Mississippi and nationwide. Because of PCP's recalcitrant nature and toxicity, it has been listed as a priority pollutant by the Environmental Protection Agency. Methods to remediate PCP in groundwater include pump and treat, filtration, and biosparging. Of these methods biosparging is the only in-situ method which substantially should reduce the remediation costs. Biosparging forces clean air under the groundwater table stimulating the indigenous microorganisms to degrade the pollutant. In this study eight biosparging wells were installed at a wood treating site in central Mississippi with contaminated groundwater. Two wells (#14 and #44) were located above and 6 wells (#42, #52, #43, #51, #41 and #17) were located beneath the air sparging lines. Water samples were collected quarterly for nutrient analysis, PCP concentration and microbial identification. In addition water samples were also collected monthly before and after nutrient amendment for microbial enumerations. Nutrients added were nitrogen, phosphorus, and potassium. After nutrient addition the largest increase in nutrient levels occurred for nitrogen and ortho-phosphorus in well numbers 52 and 17 both located near and far respectfully below the air sparging lines. Wells 52 and 17 also showed greater changes in Total Organic Phosphorus (TOP), Total Organic Carbon (TOC) and chloride ion (Cl^-) over time than the other wells. Total bacteria and PCP tolerant bacteria were highest in well # 14 located slightly above the sparge lines after eight monthly nutrient additions. PCP concentrations varied during the sampling period but did not decrease. Identification of PCP tolerant bacteria based on molecular methods revealed 17 bacterial species of which two were known PCP degraders, *Burkholderia cepacia* and *Flavobacterium* sp.

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Introduction

Groundwater quality is an important issue that affects not only the health and well being of all living things but also the economic growth and development of the state and region. More than 80% of Mississippi's total water supply is from groundwater and more than 93% of the potable water supply is extracted from water wells that tap available aquifers. (Mississippi Ground Water Resources) Approximately 2.6 billion gallons of water are pumped from aquifers in Mississippi each day of which 65% is used for irrigation, 15% used for aquaculture and 11% used for public supply. However there are no comprehensive national monitoring programs that exist to measure the full extent of groundwater contamination. State agencies indicate that groundwater contamination is a localized problem. Some reports indicate that 10% of rural domestic wells contain at least one pesticide or pesticide metabolite. One of the pesticides found in groundwater in the Mississippi Delta region is pentachlorophenol (PCP). Pentachlorophenol (PCP, Penta) is a widely used wood treatment chemical that is highly resistant to degradation. In the United States, its use was restricted in 1997 when it was classified by the EPA as a probable human carcinogen. PCP is still used in the treatment of utility poles in the United States. Prior to regulation, disposal of excess PCP, disposal of PCP treated wood waste, leakage of stored PCP, and cleanup of spilled PCP were a few issues that were of environmental concern. Because of PCP's strong resistance to degradation, it becomes a very recalcitrant contaminant when introduced to soil or water systems. The introduction of PCP in 1936 means that indigenous microorganisms may have likely developed PCP degradation mechanisms over the last 70 years (Crawford et al. 2007).

One of the most promising methods for remediation of PCP contaminated groundwater is Biosparging. Biosparging utilizes the indigenous microorganisms found in contaminated groundwater to biodegrade organic pollutants such as PCP. Clean air is injected into the contaminated zones increasing the oxygen concentration in the groundwater thereby enhancing aerobic biodegradation of the pollutant (Bass et al. 2000). Nutrients such as nitrogen, phosphorus and potassium may be added to also stimulate biodegradation. This technology can reduce the cost of remediation of contaminated sites and control the migration of contaminants into the subsurface.

The indigenous microbial community associated with the biodegradation of PCP in contaminated groundwater has not been established. This is due in part to a lack of accurate and reliable identification methods. Traditional microbial identification methods include isolation and culturing on selective media, morphological characterization, immunological responses and chemical assays (Jellison and Jasalavich 2000, Clausen 1997). However these methods have proven to be time consuming, inaccurate and incomplete. The principle limitation to the culturing of these microorganisms is the very low percentage (~ 1%) of the

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total microbial population that will grow on any one specific media (Buckley, 2004). Therefore the microorganisms that are enumerated and identified from growth media under-represent the microbes present in the soil or in the water.

The development of polymerase chain reaction (PCR, Mullis, 1987) was a critical turning point for microbial identification because it led to the development of culture-independent methods for identification of microorganisms to the species level. The power of PCR is its ability to make billions of copies of these unique DNA sequences in a short time period (Valasek and Repa, 2005). Subsequent DNA methods were developed which made use of the amplified DNA fragments generated by PCR. As a result, “DNA fingerprints” were created from the amplified DNA and used to identify microorganisms to the genus and species levels. Molecular based methods for microbial identification include Random Amplified Polymorphic DNA (RAPD), Amplified Ribosomal DNA Restriction Analyses (ARDRA), Restriction Fragment Length Polymorphism (RFLP), rDNA sequencing, Sequence-Specific Oligonucleotide Probe (Akopyanz et al., 1992, Adair et al., 2002, Jensen 1993, Jasalavich et al., 2000, Oh et al., 2003) and others. In these methods ribosomal DNA was used to study different taxonomic levels of bacteria and fungi. rDNA is a nuclear, multi-copy gene family arranged in tandem arrays that codes for the RNA subunits of the ribosome molecule. The small subunit (16S) rDNA has been shown to be highly effective for identification of bacteria. Primers designed to target the conserved regions of microbial rDNA have been used to amplify sequence variable fragments of genes or the intervening noncoding regions (Turene et al., 1999) increasing the sensitivity and selectivity for species identification. These methods work best for isolated cultures. Molecular methods for identification of mixed cultures include Terminal Restriction Fragment Length Polymorphisms (T-RFLP), Denaturing Gradient Gel Electrophoresis (DGGE), Temperature Gradient Gel Electrophoresis (TGGE), Single-Strand Conformation Polymorphisms (SSCP), or cloning coupled with DNA sequencing (Dickie, et al., 2002, Anderson and Cairney, 2004, Smit et al., 1999, Borneman and Hartin, 2000, Valinsky et al. 2002a, Valinsky et al., 2002b, O’Brien 2005).

The hypothesis for this project was that PCP degrading bacteria are present during biosparging of PCP contaminated groundwater. The objective of this proposal was to determine the bacterial community associated using cloning and sequence molecular methods for identification.

Materials and Methods

Eight biosparging wells were installed at a wood treating site in Mississippi (Figure 1). The wells consisted of 2 inch PVC pipe with a slotted screen section at the bottom of the well and positioned within the base of the saturated zone. The wells extended twenty-nine feet below ground surface. A regenerative blower was used to supply air up to 15 pounds per square inch.

Water samples (500ml) were collected quarterly for one year and

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analyzed for PCP using Gas Chromatography according to EPA Standard Methods. Beginning in December 2009, water samples were taken monthly, before and after addition of liquid nutrients (1 liter) containing 15% nitrogen, 30% phosphorus and 15% potassium and analyzed for microbial enumeration. Water samples, made to the appropriate dilutions if needed, were inoculated onto nutrient agar and nutrient agar amended with PCP and incubated for 48 hours at 28^{o}C to determine microbial enumeration. DNA was extracted from the water samples according to the protocol of the WaterMaster DNA extraction kit (Epicenter Biotechnologies, Madison WI). If the quality or quantity of DNA was not adequate for processing, microorganisms were then cultured in nutrient broth by adding 1 milliliter of water sample into 5 ml of nutrient broth while shaking overnight at 28^{o}C. From these cultures, DNA was extracted using a NucleoSpin Plant II nucleic acid purification kit from Macherey-Nagel (Bethlehem PA). The extracted DNA was amplified using bacterial 16s forward and reverse primers (5'-AGATCGATCCTGGCTCAG and 5"-GGTTACCTTGTTACGACTT). Verification of the mixed population amplified fragment was done using gel electrophoresis. The mixed fragments were cloned in *E. coli* competent cells using the TOPO TA cloning kit for sequencing (Invitrogen, Carlsbad CA). The clones were cultured in Luria broth media overnight, extracted using the Pure Link Quick Plasmid Mini Prep kit and the insert was verified by ECOR I enzyme digest. Sequencing was performed according to the Beckman Coulter DTCS Quick Start Kit (Beckman Coulter, Brea CA) and analyzed on a Beckman CEQ 8000 DNA Analysis System. The sequences were aligned using the Clustal W Multiple Sequence Alignment Program version 1.7 and analyzed data were identified using BLAST search of NCBI (Thompson et al. 1994). Sequences with a greater than 96% identity match and 3 or fewer sequence gaps were accepted as identified species.

Groundwater samples were collected quarterly and analyzed by a certified independent laboratory for total organic carbon according to EPA Method 9060 (U.S. Environmental Protection Agency), total Kjeldahl nitrogen according to EPA Method 351.4, total organic phosphorus according to EPA Method 365.3 and ortho-phosphate according to EPA Method 258.1

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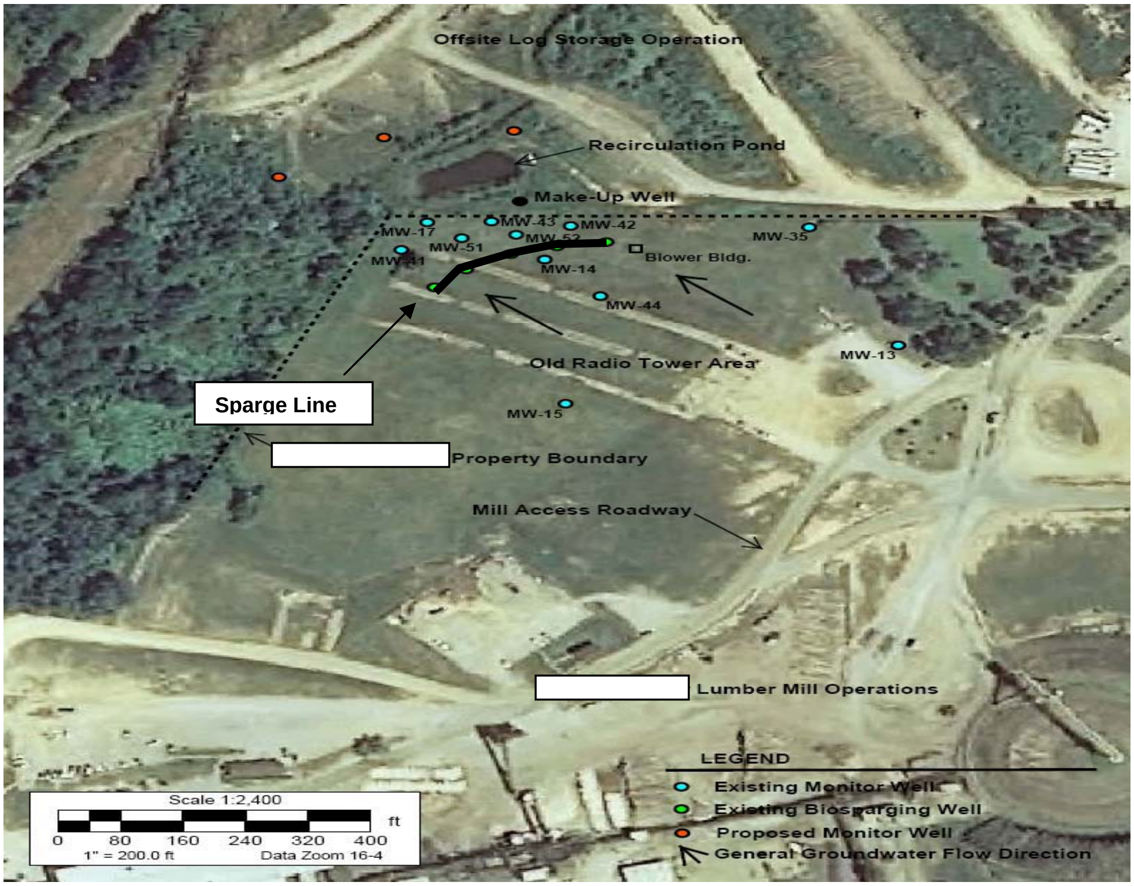

Figure1. Topographic map showing well locations. Used with permission from Lybrand Consulting, LLC.

RESULTS and DISCUSSION

Monthly nutrient additions resulted in an increase in the TKN in wells #17,# 42 and #52 (Figure 2) which were located below the sparge line. Ortho-phosphorus, and TOP were also highest in wells #17 and #52 after nutrient addition (Figures 3, 4). TOC and chloride ions (Figures 5, 6) were highest in wells #17, #51, and #52 all located below the sparge line. Total bacteria and PCP tolerant bacteria were monitored pre and post nutrient amendments (Figures 7,8). In general there was an increase in the colony forming units (cfu) of both general bacteria and PCP tolerant bacteria in each well after nutrient addition over the sampling times. For example in well # 14, located above the sparge line, there were no detectable PCP tolerant bacteria before nutrient addition and 23,000 cfu of PCP tolerant bacteria after nutrient addition. In the well below the sparge line, #51, there were 2800 cfu and 9700 cfu of PCP tolerant bacteria present before and after the nutrient addition respectfully. Extraction of DNA and cloning revealed different patterns of DNA fragments found in the groundwater samples (Figures 10,11). Four PCP tolerant bacteria were detected in well #14 compared to thirteen PCP tolerant bacteria detected in well #51(Figure 12, Table 1). Two

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bacteria, *Burkholderia cepacia* (Xun 1996) and *Flavobacterium sp* have been reported to be known PCP degraders (Topp and Hanson 1990) . *B. cepacia* is a common human pathogen that is often found in water and soil and survive for long periods of time. Some of the other organisms detected produce nitrifying and sulfur oxidizing enzymes. PCP concentration did not in general decrease over time (Figure 9) probably due to insufficient populations of PCP degrading organisms in the groundwater.

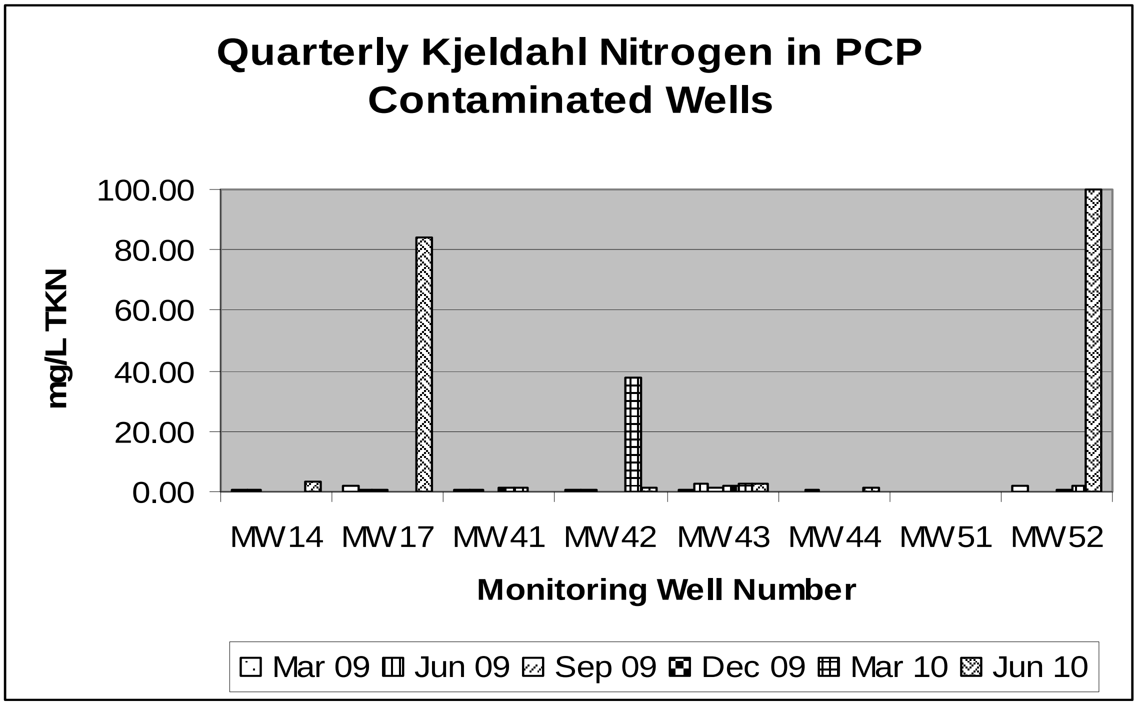

Figure 2. Kjeldahl Nitrogen in PCP contaminated groundwater collected in from eight monitoring wells over a 15 month period.

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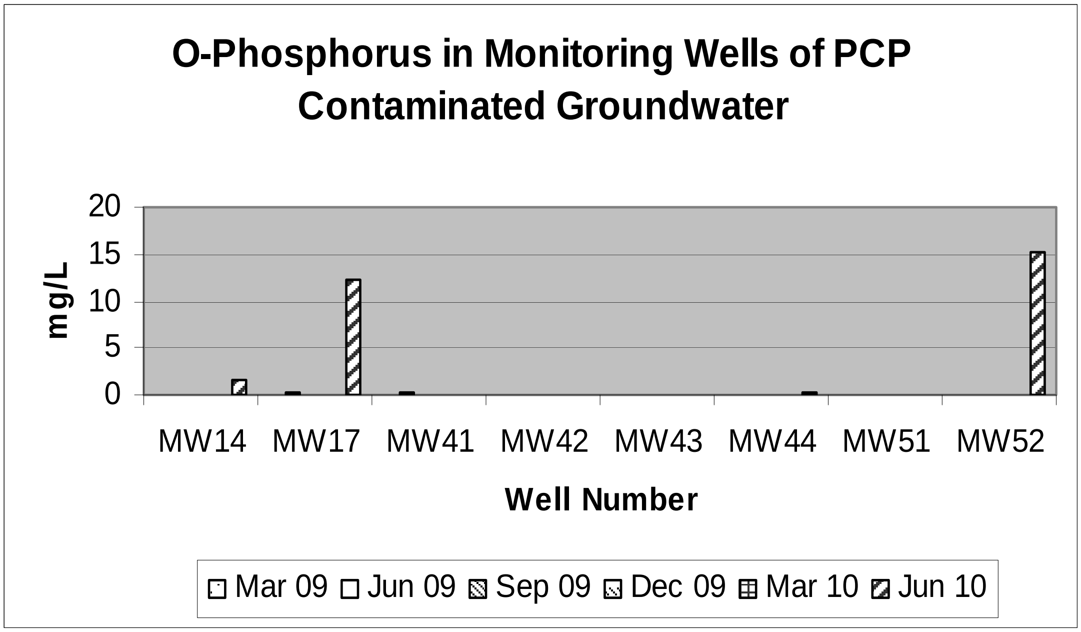

Figure 3. Ortho-phosphorus in PCP contaminated groundwater collected from eight monitoring wells over a 15 month period.

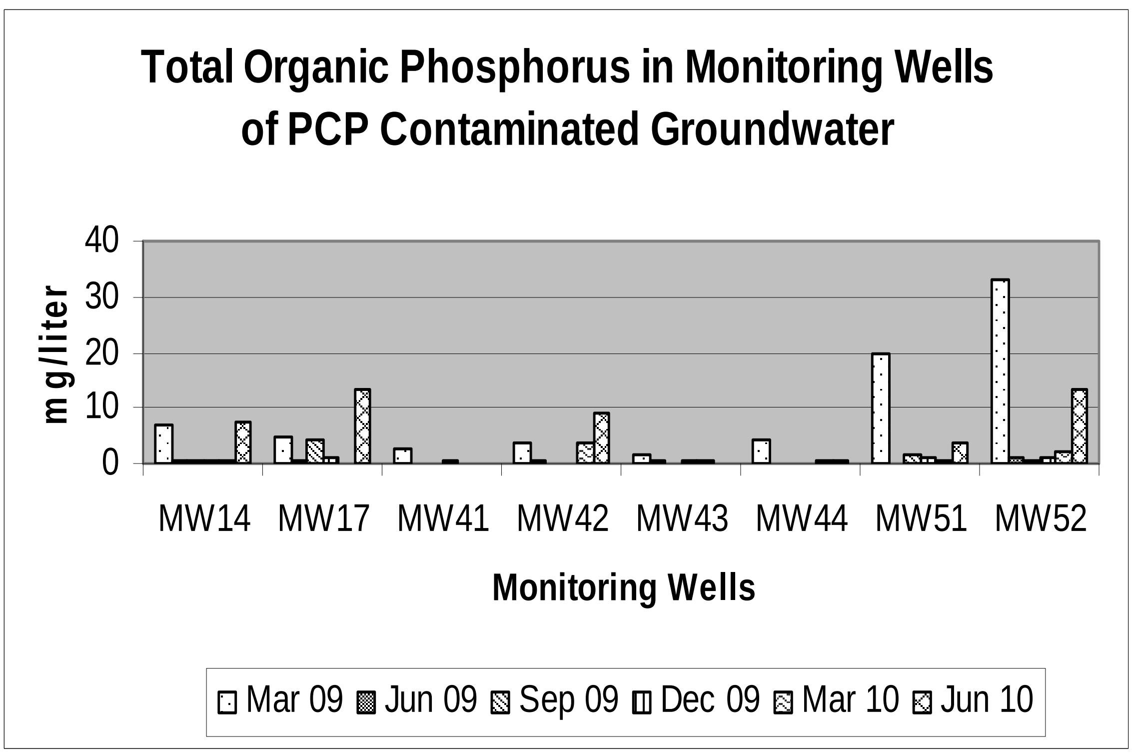

Figure 4. Total organic phosphorus in PCP contaminated groundwater collected from eight monitoring wells over a 15 month period.

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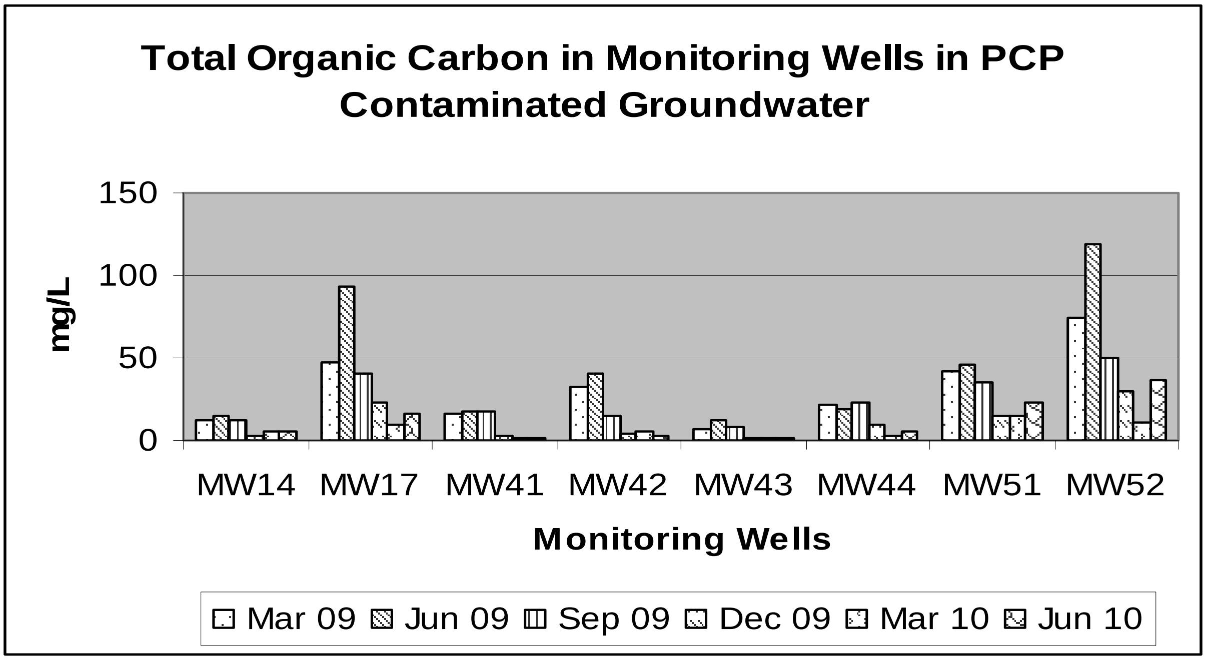

Figure 5. Total Organic Carbon in PCP contaminated groundwater collected in from eight monitoring wells over a 15 month period.

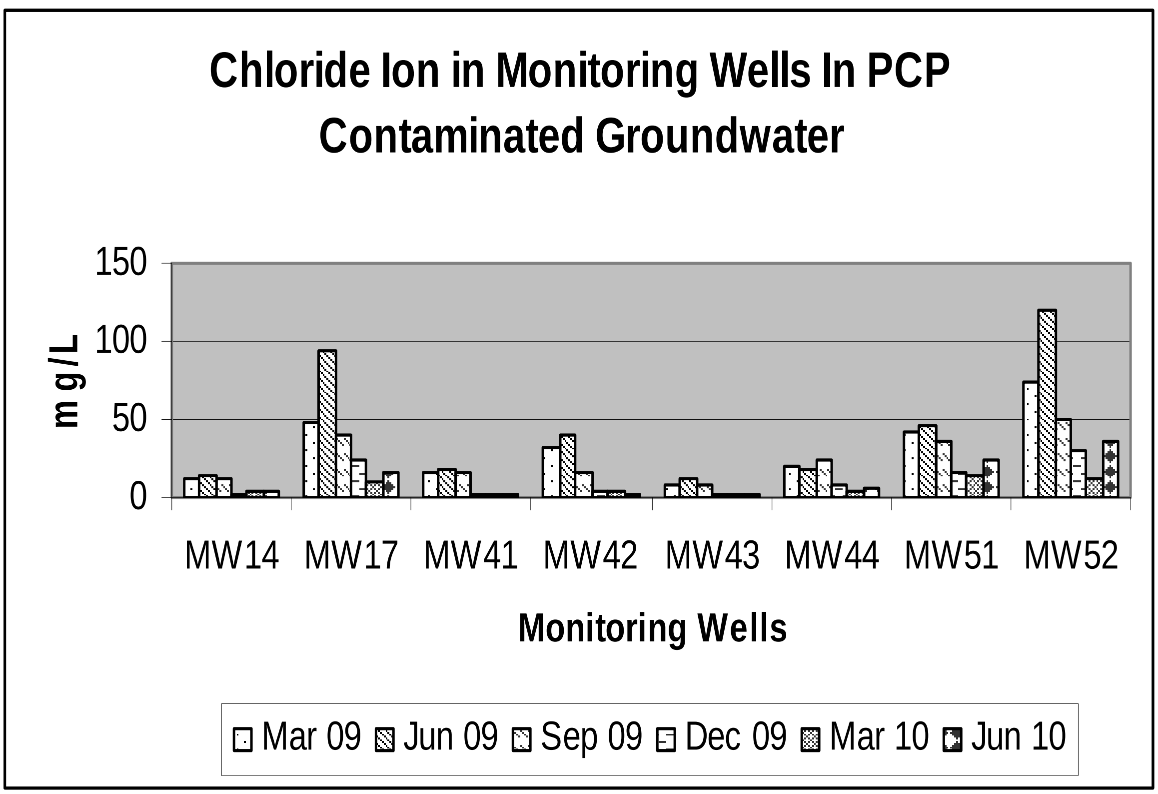

Figure 6. Chloride ion in PCP contaminated groundwater collected from eight monitoring wells over a 15 month period.

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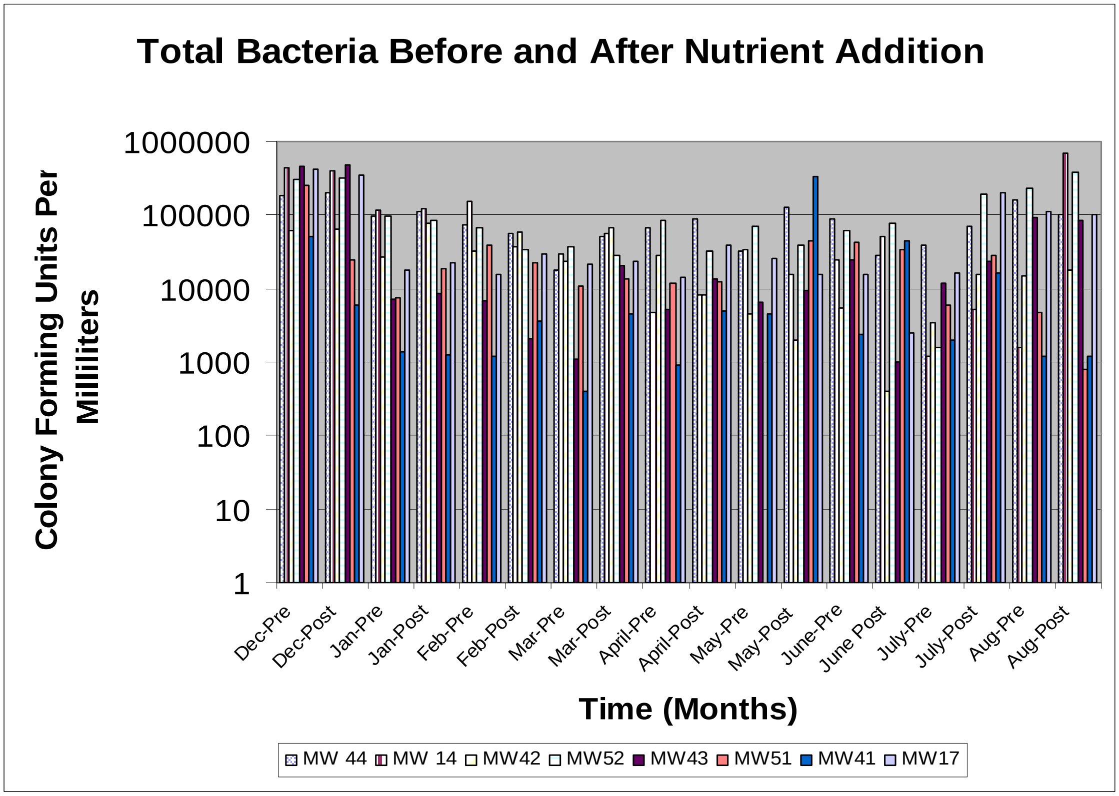

Figure 7. Total bacteria in PCP contaminated groundwater collected from eight monitoring wells.

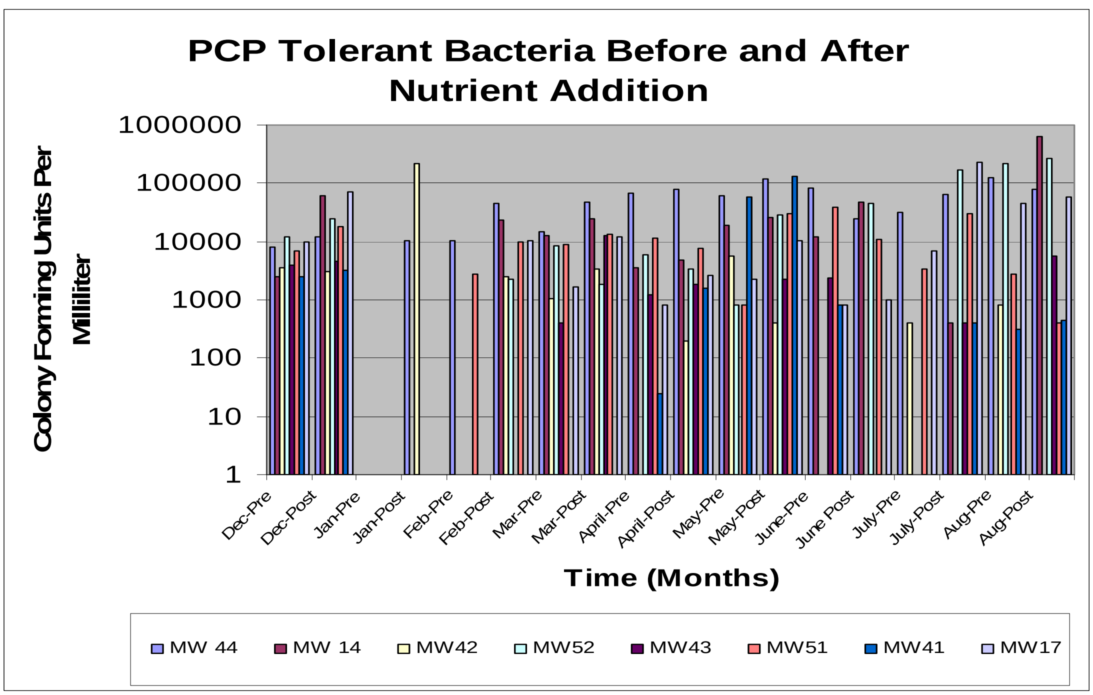

Figure 8. PCP tolerant bacteria PCP contaminated groundwater collected from eight monitoring wells.

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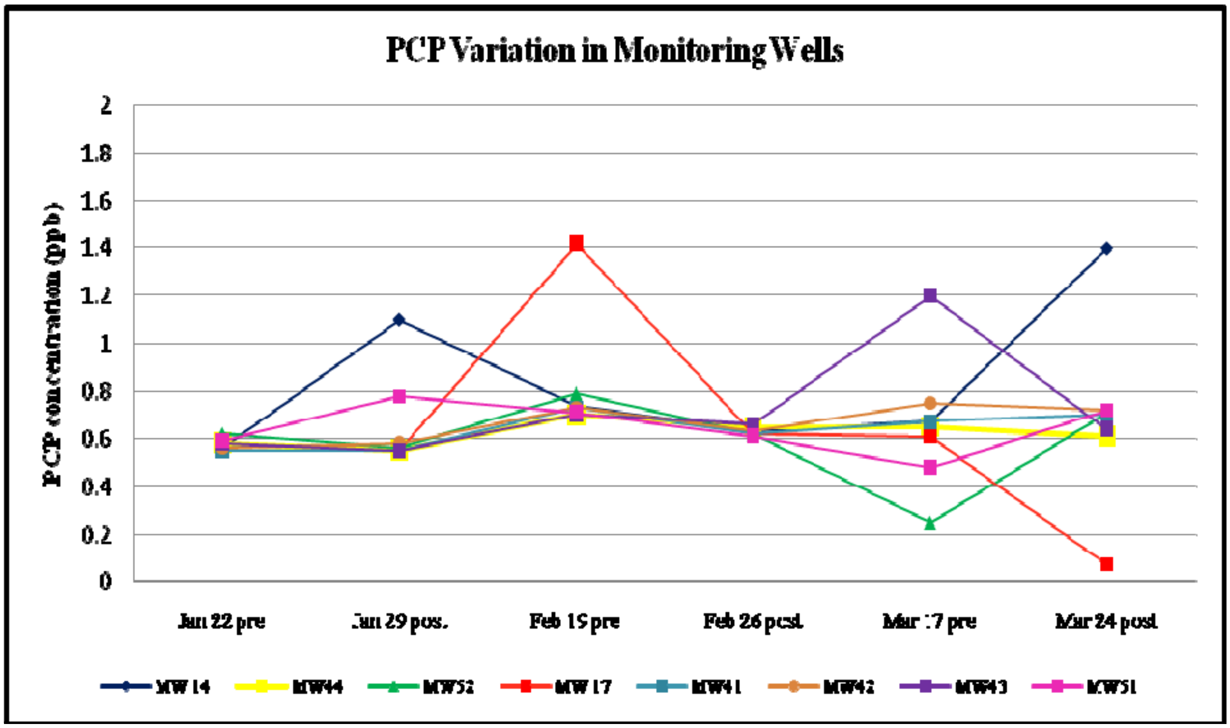

Figure 9. PCP concentration in contaminated groundwater from eight monitoring wells at selected time periods before and after nutrient addition.

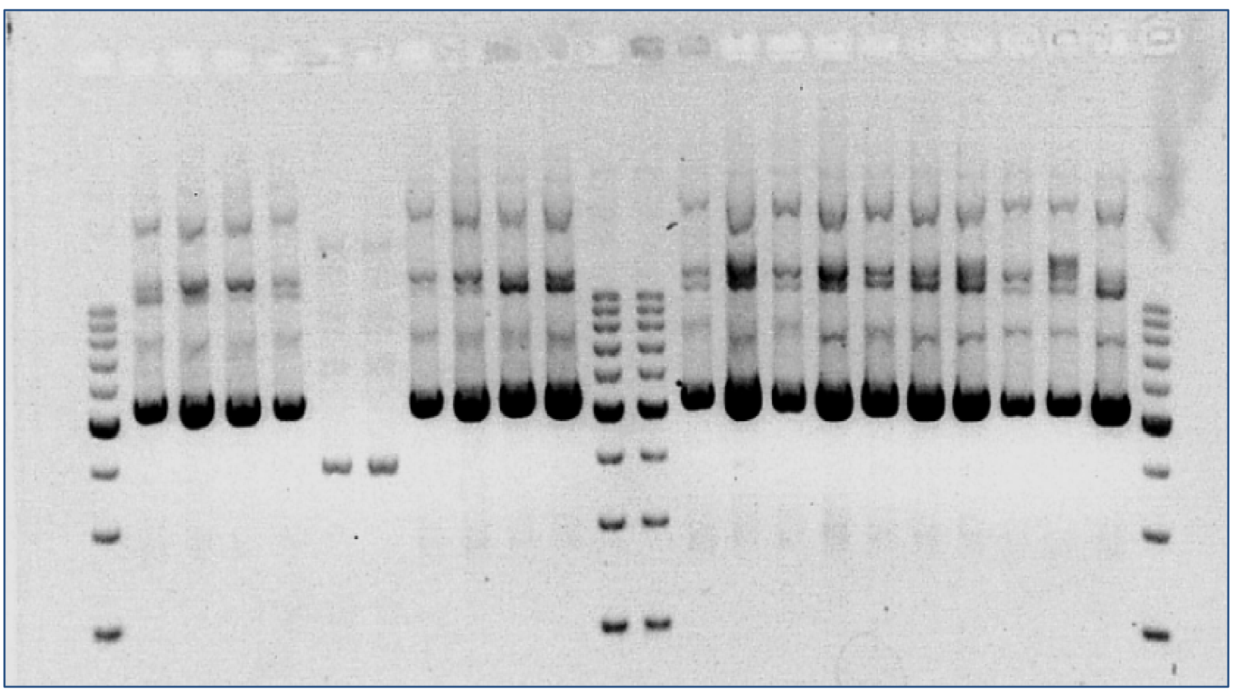

Figure 10. Extracted plasmid from clones containing the 16s region of interest for identification by sequencing. (Supercoiled DNA marker – lanes 1, 12, 13, & 24; well # 14 – lanes 2-11; well #51 – lanes 14-23)

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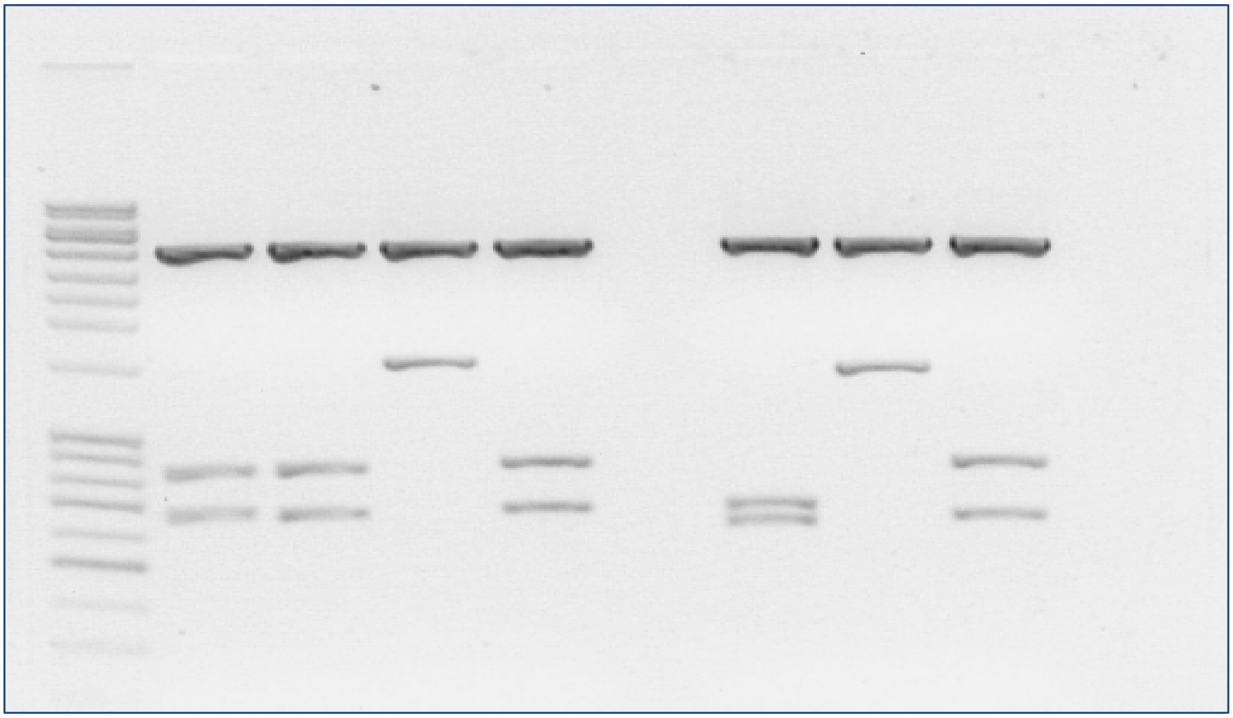

Figure 11. Digested plasmid and inserted 16s DNA fragment. (1kb DNA marker – lane 1; wells # 14– lanes 2-5; well #51 – lanes 7-9)

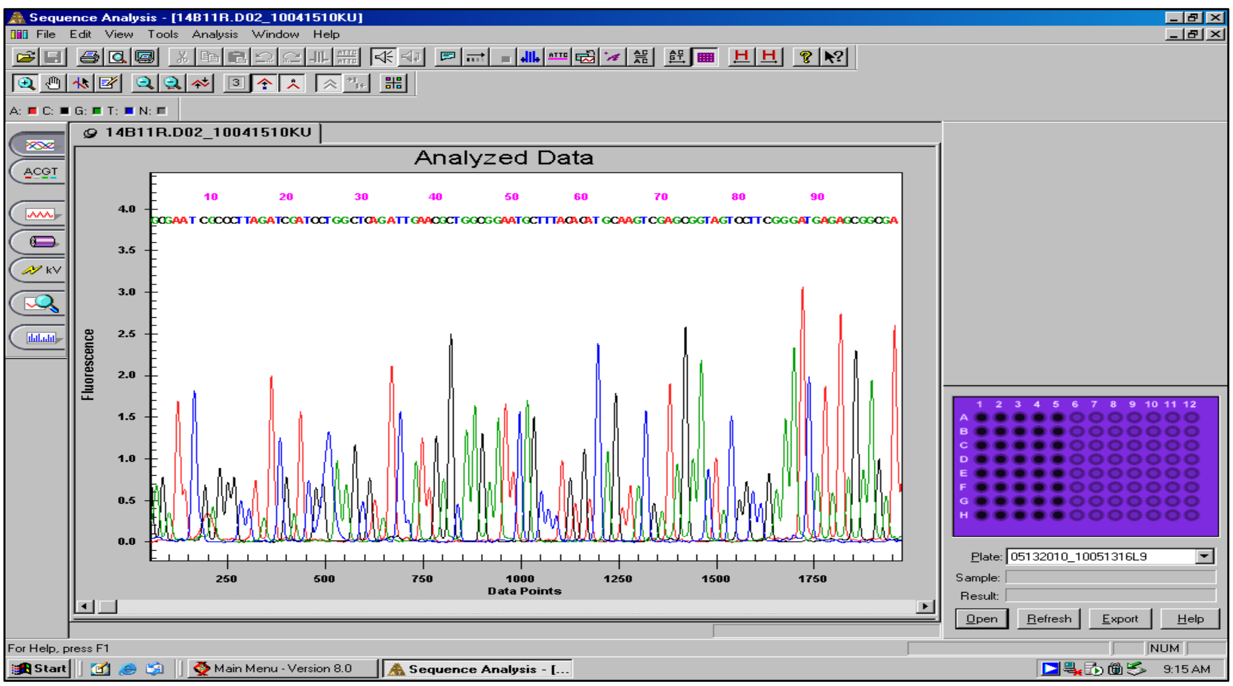

Figure 12. Sequence analysis of clone 16s fragment for identification of a PCP-degrading bacterium, *Flavobacterium sp* found in PCP contaminated groundwater**.**

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Table 1. Bacteria identified from two monitoring wells, with greater than 96% identity match and three or less sequence gaps.

Well 14 – February 2010	**Well 51 – February 2010**	
Burkholderia cepacia	*Burkholderia sp.*	*Pedobacter insulae*
Rhodanobacter thiooxydans	*Janthinobacterium lividum*	*Pedobacter duraquae*
Thauera sp.	*Duganella sp.*	*Herbaspirillum sp*
Denitratisoma oestradiolicum	*Azospirillum irakense*	*Janthinobacterium agaricidamnosum*
	Collimonas sp.	*Massilia dura*
	Flavobacterium sp.	*Aquaspirillum arcticum*
	Oxalicibacterium faecigallinarum	
** >40 Uncultured bacterial strains also found in each sample		

Conclusions

This study evaluated biosparging as a remediation tool to reduce the PCP concentration in groundwater at a wood treating site. The addition of nutrients was required in order to obtain sufficient bacteria for identification. However the bacterial population was very low and may have been insufficient to degrade PCP. Two PCP degrading bacteria were identified, *Burkolderia cepacia* and *Flavobacterium*. More studies are needed to determine if these bacteria are responsible for PCP degradation and if more nutrients will increase the population of these bacteria.

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Students Involvement

Beth Stokes, PhD student, Forest Resources, May 2011 graduation date
Min Lee, undergraduate student, Forestry, May 2011 graduation date

Publications

Proceedings of the American Wood Protection Association –in press

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Presentations

American Wood Protection Association, Savannah, GA, May 24-26, 2010
Water Resources Research Institute, Tunica MS, August 5, 6 2009.

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Sources, sinks, and yield of organic constituents in managed headwaters of the Upper Gulf Coastal Plain of Mississippi

Basic Information

Title:	Sources, sinks, and yield of organic constituents in managed headwaters of the Upper Gulf Coastal Plain of Mississippi
Project Number:	2010MS110B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Geochemical Processes, Water Quality, Nutrients
Descriptors:	None
Principal Investigators:	Jeff Hatten, Janet Dewey, Andrew Ezell

Publications

1. Quartly reports 2010-2011 submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Hatten, J., J. Dewey, C. Mangum, B. Choi, and D. Brasher, Sediment, Particulate Organic Carbon, and Particulate Nitrogen Transport in Ephemeral and Perennial Streams of the Upper Coastal Plain Mississippi, oral presentation at the 2010 Mississippi Water Resources Conference, Bay St. Louis, MS, November 3-5, 2010.
3. Jeff Hatten, Sediment, Particulate, Organic Carbon, and Particulate Nitrogen Transport in Ephemeral and and Perennial Streams of the Upper Coastal Plain Mississippi, status report to the Mississippi Water Resources Research Institute Advisory Board, Mississippi State, MS, November 9, 2010.
4. Hatten, J., J. Dewey, J., C. Mangum, B Choi, D. Brasher, 2011, Sediment, Particulate Organic Carbon, and Particulate Nitrogen Transport in Ephemeral and Perennial Streams of the Upper Coastal Plain Mississippi, 2010 Mississippi Water Resources Conference Proceedings, p. 56, http://www.wrri.msstate.edu/pdf/2010_wrri_proceedings.pdf
5. Hatten, J., J. Dewey, and A. Ezell, 2011, Sources, sinks, and yield or organic constituents in managed headwaters of the Upper Gulf Coastal Plain of Mississippi, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 14 pgs.

Project Title: Sources, sinks, and yield of organic constituents in managed headwaters of the Upper Gulf Coastal Plain of Mississippi

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Project Type: Research

Focus Categories: GEOCHE, WQL, NU

Research Category: Water Quality

Keywords: water quality, organic matter, sediment, nutrients, headwaters

Period of Performance: March 1, 2010-February 28, 2011

Cooperator: Erik B. Schilling, Senior Research Scientist for Sustainability, National Council for Air and Stream Improvement, Inc.

Congressional District: 3rd

ABSTRACT

Sediment, organic matter, and nutrients (particularly nitrogen) are the constituents that most often lead to the impaired designation for rivers in Mississippi (E.P.A. 2000). Headwater streams are very important contributors of water, sediment and nutrients to the downstream fluvial environment. Many studies of non-mountainous systems have focused on the *quantity* of particulate or dissolved forms of material (e.g. suspended solids, organic matter, and nitrogen); few have examined the *source* of this material. The relationships among origin, storage, consumption and export of organic matter (OM) with stream discharge and subsurface interflow represent significant gaps in our understanding of headwater processes. This study is part of a larger-scale study investigating the effects of silvicultural best management practices in ephemeral and intermittent drains on hydrologic function in small-scale headwaters. A 30 ha watershed located approximately 8 miles west of Eupora in Webster County, MS has been continuously monitored for water table elevation, precipitation intensity and duration, in-stream TSS, and chemical composition of water and particulates. Data were used to elucidate the transport and source/sink behavior of sediment, and dissolved and particulate forms of organic matter, in the form of nitrogen (N) and organic carbon (OC), over a broad range of hydrographic conditions. Results indicate that particulates in perennial and ephemeral-intermittent stream segments are derived from surface mineral soil horizons as a result of downcutting. The source of water in the perennial stream is dominated by ephemeral stream contributions rather than groundwater during dry periods. During the wet winter months perennial streamwater chemically resembles groundwater whereas ephemeral-perennial segments chemically resemble canopy throughfall waters. Ephemeral drains are significant contributors to downstream perennial streams, especially during dry periods; therefore it is important to consider ephemeral basins within an overall basin management plan.

INTRODUCTION

Forestland comprises 19.79 million acres (64.85%) of the total land area in MS; primary forest-based industries (e.g. logging, forestry) represent an annual contribution of $11-$14 billion to the state economy and approximately 54,000 jobs (MIFI, 2008; based on 2003 data). Much of the silvicultural activities upon which state economy depends occur in headwater catchments, thus silvicultural BMPs are designed to minimize forest-related non-point source inputs of sediment, nutrients and pesticides. In many upland-forested watersheds, surface and subsurface flow are temporally and spatially connected with respect to physicochemistry and biotic communities (Marshall and Hall Jr. 2004; Sobczak and Findlay 2002; Collins et al. 2007), however the ecological linkages between headwaters and larger order perennial streams are poorly documented. In particular, the relationships among origin, storage, consumption and export of organic matter (OM) with stream discharge and subsurface interflow represent significant gaps in our understanding of headwater processes (Wipfli et al. 2007). Sediment, organic matter, and nutrients (particularly nitrogen) are the constituents that most often lead to the impaired designation for rivers in Mississippi (E.P.A. 2000). Previous work has shown that headwater streams are very important contributors of water, sediment and nutrients to the downstream fluvial environment (Alexander et al. 2007). Many studies of non-mountainous systems have focused on the *quantity* of particulate or dissolved forms of material (e.g. suspended solids, organic matter, and nitrogen); few have examined the *source* of this material.

Organic constituents are important to aquatic ecosystems for several reasons. OM serves a vital function as a regulator of bacterial productivity, DO concentrations, nutrient cycling, and food web productivity (Sobcak and Findlay 2002). Organic matter supports macro invertebrate communities and nitrogen is a limiting nutrient in most terrestrial and aquatic ecosystems. While OM provides a number of benefits to aquatic ecosystems, it can also be a direct or indirect contributor to detrimental ecosystem processes. For example, excess terrestrial input of OM and associated nutrients (including N and C) can contribute to eutrophication which in turn can lead to hypoxia in marine/estuarine waters that are deficient in dissolved oxygen. Organic matter is also associated with many pollutants (e.g. mercury). Atmospherically-derived mercury forms strong complexes with organic matter (Ravichandran 2004; Liao et al. 2009) and is transported through erosion and fluvial processes, particularly flood or high discharge events that are responsible for transporting OC and sediment (Balogh et al. 2006 ; Babiarz et al. 1998; Caron et al. 2008). Increasing concern over food chain transfer of toxic contaminants such as methylmercury compels a greater understanding of OM sources and transfer within terrestrial watersheds.

In order to properly constrain the natural variability in these constituents and advise the development of TMDLs for impaired water bodies, it is necessary to understand the typical range in rates of delivery of sediment, carbon, and nitrogen. Understanding the source and transport of these compounds will allow us to better to determine what is “typical” and predict how forest management activities will affect sedimentation, N-capital, downstream ecosystems, pollutant transport, and C-cycling at ecosystem, regional, and global scales. Methods used in the major body of research regarding these constituents have avoided or under-sampled storm events. Storm events are primarily responsible for the transport of particulate constituents in smaller watersheds. Therefore, by under sampling these events the importance of sediment and particulate forms of carbon and nitrogen may not be realized. Shanley et al. (2008) suggested that utilization of a small-watershed approach coupled with event sampling may provide a reasonably reliable method to infer controlling processes of OM, nutrient, and contaminant cycling.

OBJECTIVES

This study presents an analysis of carbon dynamics within managed, forested headwaters in Webster County, MS. Focused sampling of storm events was conducted over a 12-month period in order to provide estimates of the timing of OC and nutrient load and subsequent transport. Data were used to elucidate the transport and source/sink behavior of sediment, and dissolved and particulate forms of organic matter, in the form of nitrogen (N) and organic carbon (OC), over a broad range of hydrographic conditions. The overall objective was to quantify the yield, source, and transport processes of OC and nutrients within managed watersheds. Specific objectives were (1) to determine the amount of sediment, OC and nutrients discharged during one year from watersheds with contrasting forestry management activities; (2) to determine the source(s) of sediment, OC, and nutrients in managed watersheds; (3) to elucidate potential change in source with changing season, management scenario and event character, and (4) to determine whether the load and character of sediment, OC, and nutrients change from intermittent to perennial stream systems.

STUDY SITE

The study was conducted at an established research site within a first-order headwater catchment located in the Hilly Coastal Plain Province of Webster County, MS. Land use at the study site primarily consists of short-rotation pine silviculture with seasonal hunting; silvicultural prescriptions range from undisturbed reference forest to heavily-trafficked clearcuts. Soils are predominately of the Sweatman series which is a fine, mixed, semiactive, thermic Typic Hapludult (McMullen et al. 1978). Soils are typically moderate to well-drained silt-loam; with a medium to high available water capacity, moderate permeability in the upper subsoil, and moderately high permeability in a fragipan at 18-38 inches depth. Precipitation is well distributed throughout the year with a 30 year mean of 1,451 mm. Mean winter temperature is 7 °C and mean summer temperature is 26 °C (U.S. National Weather Service gauge 222896 Webster, MS). A perched water table above the fragipan is common during wet seasons; depth to water table may be 12-24 inches. Hillslope water table typically drops to >2 m below the surface in the summer. Overstory vegetation is typical of forested loblolly pine (*Pinus taeda* L.) stands of similar age class with a lesser component of mixed hardwoods.

METHODS

This study is part of a larger-scale study investigating the effects of silvicultural best management practices in ephemeral-intermittent drains on hydrologic function in small-scale headwaters. Four ephemeral-intermittent drainage basins and the downstream perennial stream were selected for study. Drainage basins were monitored for duration and intensity of precipitation, streamflow, discharge, water table elevation, and total suspended solids (TSS) from March 2010 through February 2011. Samples were collected from four potential sources/sinks within the watershed (surface water, subsurface water, in-stream sediment and soil) to qualify the amount and partitioning of OC and N from the managed watershed, and to determine the relationship between organic exports and sediment yield. It is generally assumed that source areas will consist of soils and surface organic inputs to stream (e.g. vegetative litter and periphyton), that and that exports will be carried in either dissolved form via surface waters or as fine particulates associated with TSS. Groundwater at these sites may be a source or temporary sink depending on whether streams are influent or effluent at different times of the year.

Five monitoring/sampling stations were established: four ephemeral-intermittent stations and a downstream perennial stream station. Ephemeral-intermittent monitoring stations were established in January of 2007. Transects were established perpendicular to developed channels along the entire length of the ephemeral-intermittent stream segment (Figure 1) within each sub-watershed.

<u>Groundwater:</u> A total of 25 wells (5 m intervals within transect) were installed in each ephemeral-intermittent drainage basin for purposes of monitoring groundwater elevation and collecting subsurface water samples. Depth-to-water table was monitored bi-monthly with an electronic tape. Groundwater was sampled from four within each sub-watershed which best represent waters in the hyporheic zone (in-channel well), riparian zone, and from the hill slope. Standing water in wells was removed using a PVC sampling bailer, the well was allowed to recharge, and subsurface water was collected. Samples were decanted into acid-washed HDPE collection vessels, placed on ice and removed to the laboratory for analysis. Ground water was sampled 6 times throughout the year.

<u>*In situ* Surface water monitoring/sampling</u>: Surface water monitoring/sampling stations were established near the outlet of each sub-watershed. A 1.8 m length of 25.4 cm (i.d.) schedule 40 PVC was installed and stabilized with sandbags to constrain flow. Discrete samplers were installed on all ephemeral-intermittent monitoring stations. Samplers were linked to area velocity sensors mounted within 1.8m lengths of 25 cm i.d. PVC pipes. Sensors were programmed to measure level within the pipe and to trigger automated sampling continuously during rising and falling limbs of major flow events. Automatic samplers were programmed to sample at least once during the rising hydrograph, and then every 12 hours until the event ended (as determined by discharge falling below that of the initial sample). ISCO discrete samplers were programmed to collect an initial sample when stream depth is greater than 1.0 to 2.0 cm, depending on the stream and season. A fifth monitoring station consisting of a stilling

well, an area-velocity sensor and a discrete sampler was installed downstream of the ephemeral-intermittent watersheds and was similarly programmed. Grab samples from all locations were collected whenever personnel were onsite. A rating curve (discharge vs. stage) was developed for the perennial stream. A stilling well was made from 12 cm ID PVC and equipped with a pressure transducer. In-stream water and suspended solids were co-collected as 1 L grab samples. Samples were fractionated into liquid and solid components in the laboratory using 0.7 µm combusted glass fiber filters (CGFF).

Precipitation and Throughfall: Precipitation intensity and duration was measured with an ISCO 674 tipping bucket rain gauge to relate the timing and volume of rainfall events to water levels in wells and stream discharge. The rain gauge was installed in an open area, away from trees and wind. Within the ephemeral watersheds, four through-fall buckets consisting of a screened, five gallon bucket were installed to collect precipitation during major events. Throughfall samples were decanted into acid-washed HDPE collection vessels, placed on ice, and removed to the laboratory for analysis.

Soil Sampling: Soils were sampled by horizon to a depth of 1 m from several locations representing distinct topographic positions within the reference ephemeral and perennial stream watersheds (e.g stream cut-banks, side slopes, and ridges). Soils were air dried and ground to pass a 2 mm sieve for chemical analysis. Soil solution was sampled using a lateral flow sampler custom constructed from a longitudinally-sliced ISCO discrete sampler bottle connected to an HDPE collection vessel with Tygon tubing. Soil solution samplers were placed flush with the surface of mineral soil immediately beneath the O-horizon.

Sample analysis: All water samples (*in-situ* stream water, perennial grab samples, groundwater, and throughfall) were fractionated into filtered water and residual solids; resultant solids were handled similarly to soils. Water samples were filtered through weighed 0.7 µm combusted glass fiber filters (CGFF) and dried at 60°C for TSS determination. Filtered water was split into four aliquots (for UV_{254}, DOC, DIN and DON), and immediately frozen. DOC and Stable isotopes ($\delta\ ^{13}C$ and $\delta\ ^{15}N$) were determined at the Stable Isotope Facility at UC Davis. UV absorbance at 254 nm was determined using a UV spectrophotometer; absorbance was normalized by DOC content to determine Specific UV Absorbance (SUVA; a measure of DOC aromaticity). Dissolved inorganic N (DIN; NH_4^+-N_{RAW}, and NO_3^--N_{RAW}) was determined using an ion chromatograph (Dionex, Inc., Sunnyvale, CA). Solid samples (soil and filtered particulates from CGFF) were analyzed for total C and N using a dry combustion analyzer. Statistical analysis and data interpretation: SAS was used to generate summary statistical data for chemical characteristics of water and solids from streams and potential source areas. Where management scenarios were compared, means separation was tested using a general linear model (SAS Institute). Duncan's multiple range test was used to evaluate statistical significance at alpha = 0.05. Sediment source was determined through a combination of elemental ratios (OC:N), stable isotopes ($\delta\ ^{13}C$ and $\delta\ ^{15}N$), and specific ultraviolet absorbance (SUVA) of DOC. End member mixing analysis is being used to further elucidate the source of sediment, OC, and N in each ephemeral and perennial stream.

RESULTS

<u>Composition of Dissolved Constituents and Source of Water:</u> Relative contributions of throughfall and/or groundwater to streamflow can be determined using the dissolved constituent make up of each of the endmembers (throughfall and groundwater) and comparing them to the concentration of dissolved constituents in surface runoff. We measured the composition of dissolved constituents in groundwater, ephemeral and perennial streamflow, and throughfall. In general, throughfall yielded the highest dissolved inorganic N and DOC (Table 1). Inorganic N and DOC may be derived from exudates in the forest canopy as well as that present in precipitation. Groundwater was shown to have similar dissolved inorganic N when compared with ephemeral streams, suggesting that groundwater and surface stream water is routed through the soil allowing uptake and adsorption processes to occur thereby removing these constituents from the dissolved load. Both groundwater and ephemeral streams yielded higher dissolved inorganic N compared with the perennial stream, which suggests that the dissolved load is diluted with source water low in dissolved inorganic N or that the N is adsorbed or denitrified.

Dissolved organic carbon concentrations were much higher in both ephemeral and perennial streams relative to groundwater as DOC is leached from organic rich surface soil horizons through lateral surface flow. There was a strong relationship between UV absorbance and DOC concentration as a result of aromatic moieties common in DOC that absorb light in the UV spectrum (Figure 2). This relationship permits comparison of DOC concentration across many more samples and estimation of DOC concentrations across time and future events. The ephemeral streams have a high UVA relative to the perennial stream and endembers and the relative differences between the sources and streams are much smaller than for DOC alone (Table 1). The lower relative differences are probably a result of changing composition of the dissolved organic carbon. Specific ultra-violet absorbance (SUVA) provides an indication of the composition of DOC by normalizing UVA by the concentration of DOC (i.e. UVA/DOC). Groundwater yielded the highest SUVA suggesting that this pool of DOC was composed of aromatic moieties such as phenols from lignins and tannins. The DOC in groundwater typically has a low attraction to soil surfaces as a result of low charge density and are typically not favored by soil microorganisms for metabolic functions; therefore they escape oxidation and adsorption to reside in the groundwater pool. Throughfall yielded a very low SUVA suggesting that DOC in this endmember was low in aromatic carbon and that the high DOC concentrations in this endmember were a result of saccharides or other highly mobile exudates that dissolve into water as precipitation moves through the canopy. The perennial and ephemeral streams yielded similar SUVA values suggesting that while the DOC concentrations decreased from ephemeral to perennial streams the quality of this material remained relatively constant. This also suggests that the source of water in the perennial stream is dominated by the ephemeral streams, and not groundwater.

During the dry part of the year, throughfall was enriched in DOC (as UVA in Figure 3) and depleted in Cl^- while the opposite was true for groundwater. The chloride ion is a robust conservative tracer of water in watersheds. The concentrations of both Cl^- and DOC (as UVA in Figure 3) decreased for groundwater and throughfall, respectively, as soil moisture and water table height increased during the wet part of the year (winter). There was a similar trend found in SUVA and DOC-δ13C data (Figure 4); throughfall and groundwater become more similar as watersheds were exposed to greater amounts of precipitation.

Ephemeral streamflow during storm events require significant antecedent moisture present during the winter and spring; therefore the chemical composition of stream water was similar to groundwater and throughfall during the wet parts of the year. The overall composition of water in the ephemeral and perennial channels was not very different; however, there do appear to be some minor differences in the source of water between the ephemeral and perennial streams.

In general, perennial streams appear to have a dissolved composition that more closely resembles groundwater while the composition of water in ephemeral streams resembles that of throughfall (Figures 3 and 4).

While we have only assessed one replicate of watersheds we have sampled many storms from which we can examine potential treatment effects of harvesting and BMP design on the chemical composition of stream water (Table 2). In general, the uncut stand yielded lower DOC concentrations and the DOC present yielded a higher contribution of aromatic compounds as evidenced by higher SUVA. These results may be due to alterations in the microclimate of the cutover stands which leads to production and leaching of DOC and subsequent depletion in aromatic materials. There was also found a significant increase in nitrate concentrations in the cutover stands, probably as a result of a decrease in uptake (from the clearcut) and a high level of mobility of nitrate in soils. The reference may have yielded a higher concentration of Cl^{-} as a result of higher rates of evapotranspiration.

Composition of Particulate Constituents and Source of Sediment: Soil is the ultimate source of sediment, but may be derived from overland transport of surface soils or mobilization of deeper soils through downcutting and pipeflow. Since organic matter is a dynamic constituent of soils and sediment we can use it to trace the source from which sediment is being derived within the watershed (i.e. the last soil profile of residence). Organic and mineral soils were examined from both near- and distal-stream topographic positions. Organic soil horizons were by definition higher in %C compared with mineral soils (Table 3). Organic soil horizons also yielded a higher C:N than mineral soils and were depleted in both $\delta^{13}C$ and $\delta^{15}N$ relative to mineral soil. There were also trends within the mineral soils in which A horizons typically yielded higher %C and C:N and were more depleted in $\delta^{13}C$ and $\delta^{15}N$ as compared with B and C horizons (Figures 5 and 6). The differences in composition among soils horizons provide information as to the source of sediment and erosion processes.

Suspended sediments from ephemeral and perennial streams appears to have a stable isotopic composition that is similar to soil A horizons (Figure 5). The C:N of these sediments more closely resembles that of B and C horizons (lower than A horizons), however, the carbon concentration is much too high to be derived from these deeper soil horizons. This trend may be partially satisfied by inputs of organic detritus from O horizons, but the suspended sediment does not appear to be a binary mixture of organic and deeper mineral soils. Our working hypothesis is that the suspended sediments are being derived from surface mineral soil horizons (A horizons) but that there is a preferential transport of smaller clay sized particles which may contain both high carbon and low C:N ratio. Further analysis (e.g. density and size fractionation) is needed to confirm or refute this process.

Table 1. Chemical characteristics in water from five sources within headwaters of Webster County, MS.

Parameter	Groundwater			Perennial stormwater			Ephemeral stormwater			Soil solution			Throughfall		
	n	mean	stderr	n	mean	stderr	n	mean	stderr	n	mean	stderr	n	mean	stderr
UVA	46	0.18	0.03	38	0.13	0.02	84	0.40	0.03	.	.	.	27	0.31	0.07
SUVA	10	0.11	0.04	12	0.04	0.01	28	0.04	0.00	.	.	.	8	0.02	0.00
DOC	10	1.67	0.27	12	6.57	1.45	29	12.57	1.27	.	.	.	8	31.09	13.78
DOC_13_pdb	10	-29.09	0.62	12	-28.70	0.24	29	-29.14	0.10	.	.	.	8	-29.73	0.72
NO3	40	0.59	0.23	33	0.10	0.03	68	0.60	0.16	.	.	.	24	1.31	0.34
NH4	60	0.15	0.03	55	0.07	0.01	123	0.13	0.02	3	0.30	0.30	37	0.18	0.02
N_dissolved	60	0.20	0.04	55	0.07	0.01	123	0.18	0.03	3	0.24	0.24	37	0.33	0.06
TSS	.	.	.	48	88.99	40.68	120	197.63	43.48	.	.	.	.	.	.

Table 2. Chemical characteristics of ephemeral streamwater by forest management treatment within headwaters of Webster County, MS. Means within a row followed by the same letter are not significantly different according to Duncan's Multiple Range test.

Parameter	**Ephemeral stormwater by treatment**															
	NO BMP				BMP1				BMP2				REF			
	n	mean		stderr	n	mean		stderr	n	mean		stderr	n	mean		stderr
UVA	9	0.67	**a**	0.09	17	0.42	**b**	0.06	37	0.38	**b**	0.05	21	0.29	**b**	0.06
DOC	7	19.41	**a**	1.84	9	14.80	**a**	0.93	6	6.72	**b**	2.33	7	7.87	**b**	2.22
DOC_13_pdb	7	-29.14	a	0.12	9	-29.05	a	0.07	6	-29.44	a	0.19	7	-29.01	a	0.36
SUVA	6	0.04	**ab**	0.00	9	0.03	**ab**	0.00	6	0.03	**b**	0.00	7	0.05	**a**	0.01
Cl	9	1.66	**b**	0.44	17	1.72	**b**	0.23	37	2.22	**b**	0.11	22	2.84	**a**	0.20
NO3	9	1.99	**a**	1.11	12	0.15	**b**	0.08	35	0.58	**b**	0.09	12	0.06	**b**	0.02
NH4	12	0.07	a	0.03	19	0.07	a	0.02	44	0.15	a	0.04	48	0.16	a	0.05
N_dissolved	12	0.39	**a**	0.19	19	0.07	**b**	0.02	44	0.22	**ab**	0.04	48	0.13	**b**	0.04
TSS	11	187.94	a	50.28	16	55.81	a	14.68	43	157.65	a	55.13	50	279.52	a	91.36

Table 3. Chemical characteristics of solid materials from five source areas within headwaters of Webster County, MS.

Parameter	Mineral soil			Organic soil			Ephemeral POM			Perennial POM			Channel sediment		
	n	mean	stderr	n	mean	stderr	n	mean	stderr	n	mean	stderr	n	mean	stderr
Sed_TotN	27	0.29	0.24	4	0.93	0.075	35	0.37	0.03	19	0.48	0.06	1	0.03	.
Sed_TotC	27	4.16	3.43	4	38.44	2.143	35	3.67	0.46	19	4.76	0.58	1	0.46	.
C/N	27	13.86	0.97	4	41.56	1.47	35	9.73	0.54	27	13.86	0.97	1	16.21	.
Sed_d13C	29	-26.27	0.23	4	-29.86	0.16	32	-27.52	0.19	2	-27.66	0.21	1	-28.99	.
Sed_d15N	29	3.68	0.30	4	-3.24	0.59	32	0.90	0.22	2	1.00	0.63	1	1.42	.

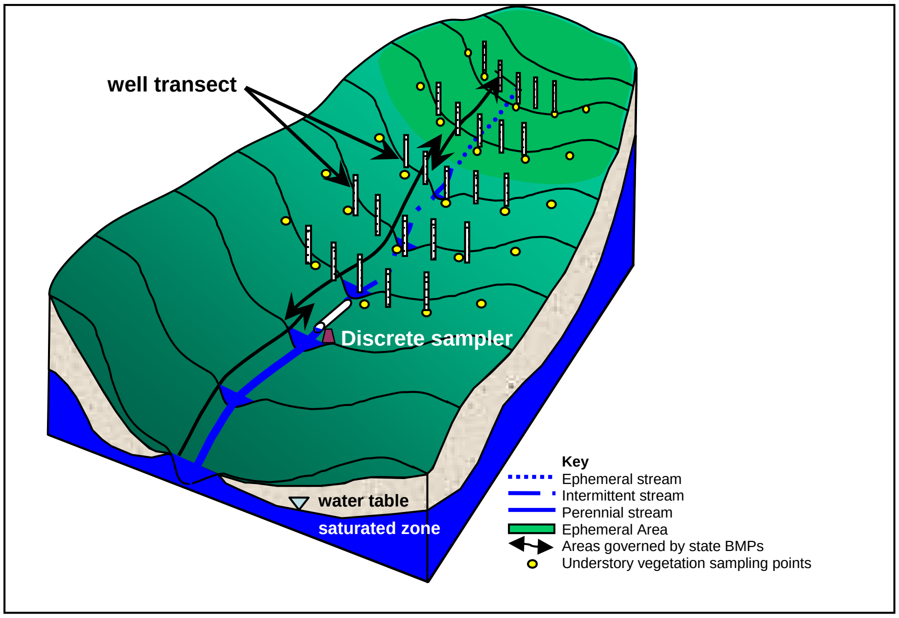

Figure 1. Schematic of an ephemeral-intermittent channel monitoring station in Webster County, MS.

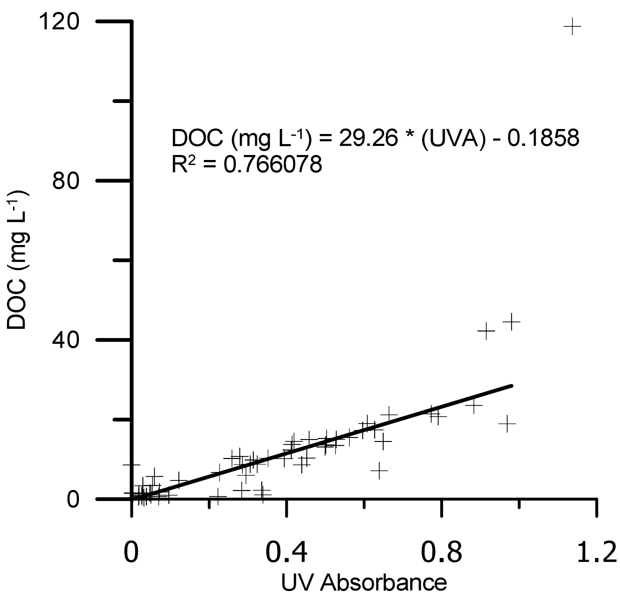

Figure 2. Relationship of UVA and DOC concentration within headwaters of Webster County, MS.

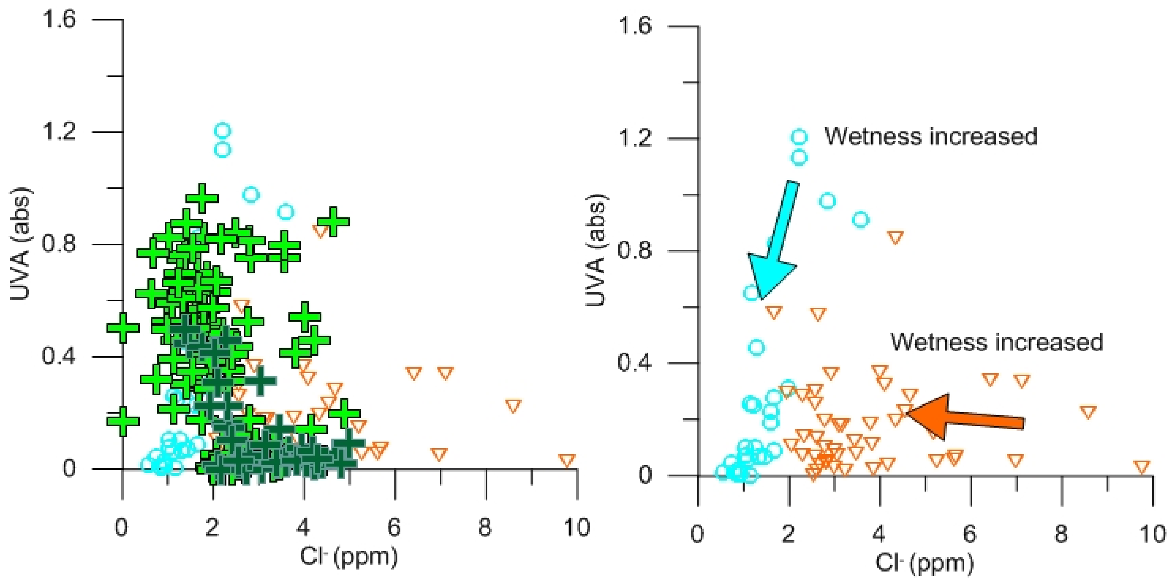

Figure 3. UVA and chloride concentration of groundwater (orange triangles), throughfall (blue circles), ephemeral stormflow (light green crosses), and perennial stormflow (dark green crosses) stream water samples. Arrows indicate changes in chemical composition as soil moisture and water table height increased into the “wet-season” for groundwater (orange) and throughfall (blue).

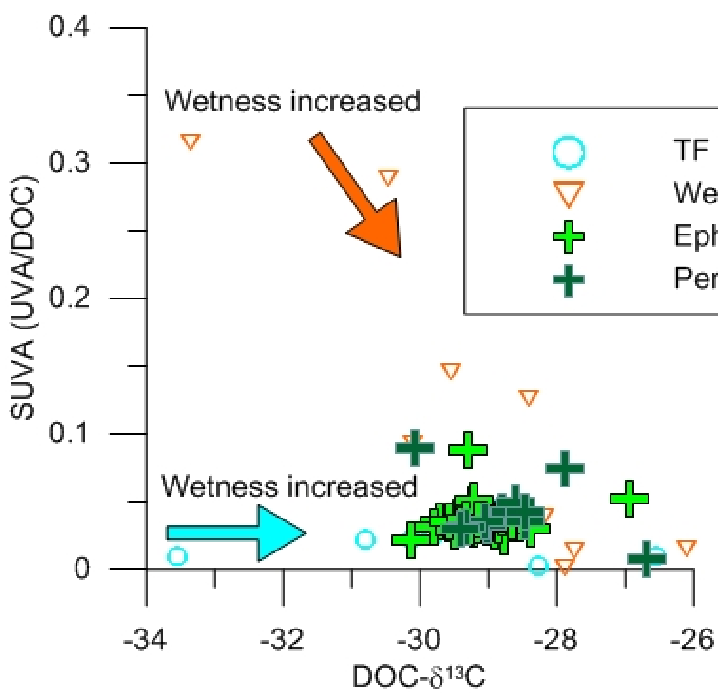

Figure 4. SUVA and DOC-δ^{13}C composition of groundwater (orange triangles), throughfall (blue circles), ephemeral (light green crosses), and perennial (dark green crosses) stream water samples. Arrows are describing trends in groundwater (orange) and throughfall (blue) composition as soil moisture and water table height increased into the “wet-season”.

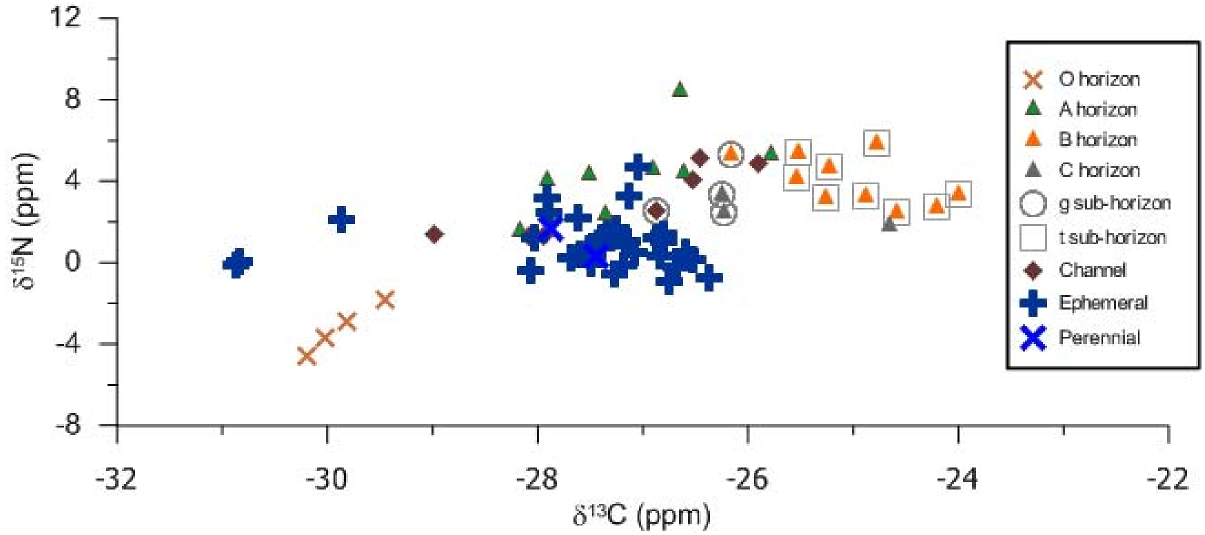

Figure 5. Stable isotopic composition of organic soil, mineral soil, perennial stream sediment and ephemeral stream sediment.

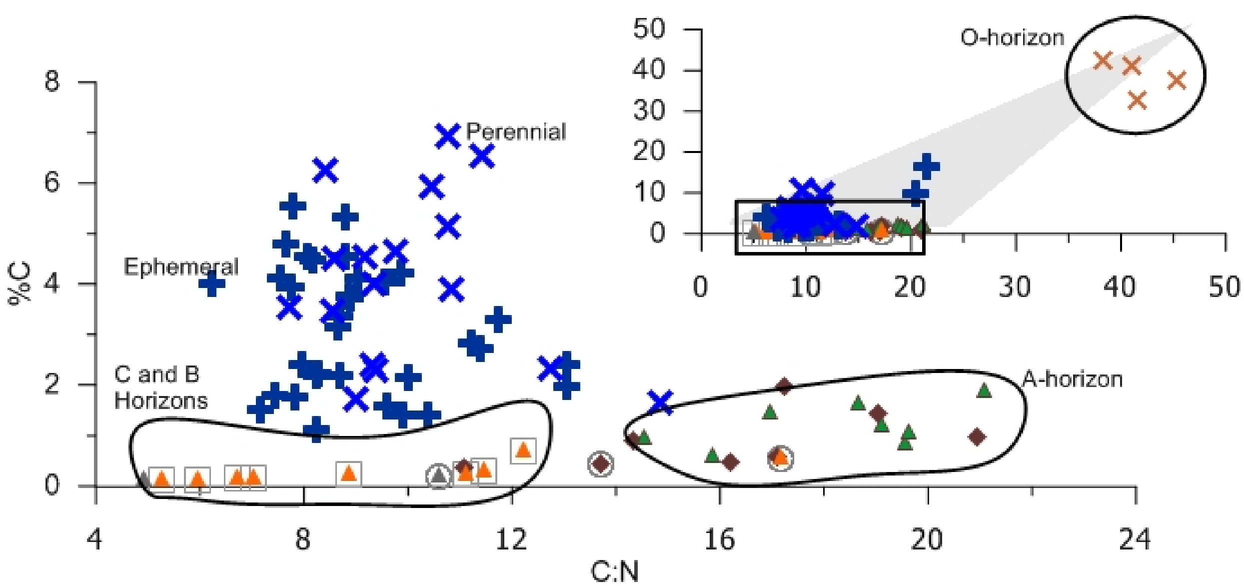

Figure 6. Carbon concentration and C:N of organic and mineral soil horizons and suspended sediments from perennial and ephemeral streams.

DISCUSSION

The load of TSS in river systems often has a positive exponential relationship with discharge, thus storm events are often responsible for the majority of solid transport (Miller and Orbock-Miller 2007). However, much of the research on POM has focused on conditions that may affect biologic components of stream systems (base and moderate flow), but have neglected storm flow (e.g. Jones Jr. and Smock 1991). The source of POM (POC and PON) is considered to be similar to the source of sediment. It is often thought that during baseflow conditions POM is derived from in-stream sources (e.g. algae; Ittekkot 1988; Hilton et al. 2008; Hatten et al. 2010). During moderate discharge conditions the source shifts towards near-stream terrestrial sources (e.g. riparian areas). As discharge progresses towards and past flood stage, the source shifts to more distal areas of the watershed (e.g. hillslope). In addition, some watersheds exhibit a hysteresis (similar to DOM) during events due to POM source limitations, and also as the source of POM shifts throughout the event (Coynel et al. 2005). In watersheds of the study area, POM was used as a proxy for sediment. Chemical composition of POM indicates that stream sediments are being derived from surface mineral soil horizons through processes of channel cutting, and that there is a preferential transport of fine carbon-rich particles downstream.

Dissolved organic matter and inorganic forms of nitrate and ammonium often exhibit a flushing effect; that is, their concentration is often highest during the rising limb of an event's hydrograph but much lower on the falling limb (i.e. clockwise hysteresis; McGlynn and McDonnell 2003). At the onset of a precipitation event, runoff and dissolved constituents are dominated by inputs from carbon and nutrient-rich riparian areas. As an event progresses, the contribution of dissolved constituents and water increases from areas with lower nutrient and carbon content and longer pathways (e.g. deeper soil horizons and hillslopes). In watersheds of the study area, nitrogen existed primarily in the form of ammonium and nitrate. Dissolved N loads in streamwaters were lower than those found in groundwater, throughfall, or leachate indicating that as waters are routed through soils en-route to stream channels, N components are removed from the dissolved load through adsorption. One of the primary findings to date is that the source of storm water in the perennial stream is primarily from ephemeral streams; therefore it is worthwhile protecting these low order drainage basins as they may be a key to water quality and habitat within perennial streams.

SIGNIFICANT FINDINGS

- During dry seasons, the source of water in the perennial stream is dominated by the ephemeral streams rather than groundwater.
- During wet seasons, dissolved composition of water in the perennial stream more closely resembles groundwater; dissolved composition of water in ephemeral streams resembles that of throughfall.
- Ephemeral channels receiving some sort of best management practice provided better protection for streamwaters than those receiving no protection.
- Suspended sediments and particulates in stormwaters are being derived from shallow mineral soil horizons (A horizons) but that there is a preferential transport of smaller clay sized particles.
- Channel erosion rather than hillslope sediment movement is indicated as the primary mechanism for sediment introduction to streams.
- Chemical characteristics of POM are useful as a proxy for determining sediment source and flux within headwaters of this region.

FUTURE RESEARCH

Water and sediment samples from these watersheds will be collected through the end of May, 2011. These samples will be analyzed for dissolved organic and inorganic composition. At the completion of this work we will have more than one full water year of samples that can be analyzed for seasonal and hydrograph trends. We will use end member mixing analysis to determine the proportional composition of each stream sample collected.

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TRAINING POTENTIAL

This project employed one master's level graduate student and four part time undergraduate researchers. Results of this research have been presented at the following:

Hatten, J., Dewey, J., Mangum, C., Choi, B., and Brasher, D. 2010. Sediment, Particulate Organic Carbon, and Particulate Nitrogen Transport in Ephemeral and Perennial Streams of the Upper Coastal Plain Mississippi. Mississippi Water Resources Conference. Bay St. Louis, MS.

Hatten, J., Dewey, J., Mangum, C., Choi, B., and Brasher, D. 2010. Sediment, Particulate Organic Carbon, and Particulate Nitrogen Transport in Ephemeral and Perennial Streams of the Upper Coastal Plain Mississippi. Mississippi State University. College of Forest Resources Advisory Board Meeting. Starkville, MS.

A Master's Thesis is expected in June 2012. Two publications (one on sediment and one on water) from this research will be submitted for publication to a journal such as Water Resources Research.

Water quality and other ecosystem services performed in wetlands managed for waterfowl in Mississippi

Basic Information

Title:	Water quality and other ecosystem services performed in wetlands managed for waterfowl in Mississippi
Project Number:	2010MS111B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3rd
Research Category:	Biological Sciences
Focus Category:	Wetlands, Economics, Water Quantity
Descriptors:	None
Principal Investigators:	Richard Kaminski, Amy B. Spencer

Publications

1. Quarterly reports 2010-2011 submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Spencer, A.B. Crayfish harvest potential from reclaimed catfish ponds, Natural Resources Enterprises workshop, June 16, 2010, Stoneville, MS.
3. Spencer, A. B., R. M. Kaminski, L. D'Abramo, and J. Avery, Crayfish harvest: An ancillary ecosystem service provided by moist-soil management oral presentation at the International Association of Astacology, July 18-23, 2010, Columbia, MO.
4. Spencer, A.B., R.M. Kaminski, J.L. Avery, L. D'Abramo, and R. Kröger, Ancillary ecosystem services from moist-soil wetlands, oral presentation at the 2010 Mississippi Water Resources Conference, November 3-5, 2010, Bay St. Louis, MS.
5. Spencer, A.B., R.M. Kaminski, J.L. Avery, L. D'Abramo, R. Kröger, 2010, Ancillary ecosystem services from moist-soil wetlands, oral presentation made to Wetlands and Waterfowl students from University of Tennessee, Starkville, MS.
6. Alford, A.B., R.M. Kaminski, R. Kroger, 2011, Water quality of effluent from managed wetlands in an agriculture landscape, poster presentation given at the Southeastern Natural Resources Graduate Student Symposium, Starkville, MS.
7. Spencer, A.B., R.M. Kaminski, J.L. Avery, L. D'Abramo, and R. Kroger, 2011, Ancillry ecosystem services from moist-soil wetlands, 2010 Mississippi Water Conference Proceedings, p. 90, http://www.wrri.msstate.edu/pdf/2010_wrri_proceedings.pdf.
8. Kaminski, R.M., A.B. Alford, 2011, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 15 pgs.

Project Title: Water quality and other ecosystem services from wetlands managed for waterfowl in Mississippi

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Cost-Share Funds Spent: $24,479

Technical Abstract

A successful and increasingly applied conservation practice in the Lower Mississippi Alluvial Valley (MAV) to mitigate loss of wetland wildlife habitat and improve water quality has been development and management of "moist-soil wetlands." This conservation practice has the potential to provide ecosystem services critical to restoring wetland functions in the MAV such as reducing dispersal of sediments and nutrients into surrounding watersheds. Moreover, a significant potential exists for native crayfish (*Procambarus* spp.) harvest in moist-soil wetlands in the MAV. During spring 2010, we estimated average daily yield of crayfish from 15 moist-soil wetlands in Arkansas, Louisiana, and Mississippi. Average daily yield of crayfish in 2010 was 2.18 kg ha^{-1} (CV = 30%, $n = 15$). This estimate was slightly greater and more variable than the estimated yield from Mississippi wetlands in 2009 (i.e., 1.75 kg ha^{-1}; CV = 16%, $n = 9$). An apparent trend in increased yield and size of individual crayfish from wetlands in Louisiana likely caused the increased yield in 2010. In July 2010, we installed water quality monitoring stations at 5 wetlands and 5 agriculture fields. Due to severe drought, water samples could not be collected from these locations until late fall 2010. Storm events that caused significant effluent discharged from wetlands greatly increased the nutrient and sediment export from these wetlands. However, concentrations of pollutants were typically lower in wetlands compared to agriculture fields. We continue to collect water samples and discharge data to calculate loads of pollutants exported during storm events. Quantifying these ancillary ecosystem services of moist-soil wetlands will encourage further establishment and management of these wetlands in the MAV and elsewhere for wildlife and associated environmental and human benefits.

INTRODUCTION

Loss of wetlands in the MAV has reduced surface water quality (e.g., Mitsch et al. 2005, Shields et al. 2009). To address loss of ecosystem services, ecologists and wildlife managers have encouraged best management practices (Maul and Cooper 2000, Stafford et al. 2006, Manley et al. 2009) and reestablishment of wetlands (Mitsch et al 2005, Kovacic et al. 2006, Kross et al. 2008) throughout the Mississippi River drainage. A successful management practice in the MAV to address loss of wetland wildlife habitat has been the establishment of moist-soil wetlands. Moist-soil wetlands are naturally vegetated basins, usually by herbaceous annuals (e.g., grasses, sedges), that are prolific producers of seeds and tubers. Because moist-soil wetlands can provide 4-10 times the carrying capacity of harvested agriculture fields in MAV (Kross et al. 2008), management of these habitats is encouraged to meet the goal of sustaining continental populations of waterfowl under the North American Waterfowl Management Plan (United States Fish and Wildlife Service 1986).

Additionally, within the MAV, strategic location of moist-soil wetlands amid farmed landscapes can reduce dispersal of sediments and other nutrients into surrounding watersheds. Predictions have been made regarding the environmental significance of this conservation practice relative to improving surface water quality in the MAV (Mitsch et al. 2005, Murray et al. 2009). However, to our knowledge, no effort has been made to quantify the success of this conservation practice to meet the goals of federal environmental quality mandates such as the Clean Water Act (CWA).

In addition to benefits provided by living plant material in moist-soil wetlands (e.g., carbon sequestration), seasonal flooding promotes decomposition of senescent vegetation (Magee 1993). Crayfish feed on the microbial consumers of detritus and other macroinvertebrates found in wetlands (Alcorlo et al. 2004). Thus, creating and managing moist-soil wetlands have propensity to provide significant habitat and forage for crayfish, opportunities for crayfish production and harvest, and additional economic gain for landowners (McClain et al. 1998). Harvest of crayfish for human consumption is significant, amounting to $115 million annually in the southern United States (Romaire et al. 2004). However, traditional crayfish-harvest operations incur considerable costs. Crayfish must be stocked annually into rice or other impounded fields. A sustainable crayfish-harvest from naturally occurring populations in moist-soil wetlands is a likely a cost-effective alternative.

OBJECTIVES

Our project is designed to identify additional ecosystem services provided by public- and private-sector management of naturally and artificially flooded moist-soil wetlands in the Mississippi Alluvial Valley (MAV). Specifically, the second year of our three-year study was designed to (1) estimate production of crayfish populations in moist-soil wetlands and (2) quantify and compare nutrient and sediment concentrations discharged from moist-soil wetlands and adjacent agriculture fields. We completed the first year of our field research during March-June 2009. We expanded our crayfish harvesting efforts during April-June 2010 to include wetlands throughout the MAV. We began our effluent monitoring in July 2010. We are currently harvesting crayfish and will continue to monitor effluent water quality through 2011.

METHODS

Study Sites

We identified 15 moist-soil wetlands on public and private lands in Arkansas, Mississippi, and Louisiana that were appropriate for our crayfish harvest research. Locations of the wetlands were: Cache River National Wildlife Refuge, Brinkley, Arkansas; Wappanocca National Wildlife Refuge, Turrell, Arkansas; Coldwater National Wildlife Refuge, Charleston, Mississippi; Property of Dr. Ronal Roberson, Tippo, Mississippi; Morgan Brake National Wildlife Refuge, Tchula, Mississippi; Panther Swamp National Wildlife Refuge, Yazoo City, Mississippi; Yazoo National Wildlife Refuge, Hollandale, Mississippi, Noxubee National Wildlife Refuge, Brooksville, Mississippi; the Property of Mr. C. Clark Young, West Point, Mississippi; Tensas National Wildlife Refuge, Tallulah, Louisiana; Catahoula National Wildlife Refuge, Jena, Louisiana; and Grand Cote National Wildlife Refuge, Marksville, Louisiana. Managed moist-soil wetlands varied in area (1-8 ha), were fallowed cropland or idled ponds, and had functioning water control structures and levees.

To monitor water quality of effluents from moist-soil wetlands, we identified 5 wetlands in the north Delta region of Mississippi. The locations of these wetlands are: Tallahatchie National Wildlife Refuge, Macel, Mississippi; Property of Dr. Ronal Roberson, Tippo, Mississippi; Charleston Farms Wetland Complex, Charleston, Mississippi; Lone Cypress Wetland Complex, Oxberry, Mississippi; and Property of Mr. Robert Brittingham, Dwiggins, Mississippi.

Field and Analytical Methods

We estimated yield of crayfish in moist-soil wetlands from April to June 2010. We set baited pyramid-style crayfish traps at a density of 25 traps ha^{-1} (i.e., traps were set 20 m apart). Traps were baited and checked for crayfish after 24 hours. All crayfish in traps were taken back to the lab where individuals were sexed, identified to species, weighed (g), and measured for carapace length (mm).

We monitored nitrate (NO_3-N) nitrite (NO_2-N), ammonium (NH_3-N), dissolved inorganic phosphorus (DIP), particulate phosphorus (PP), total inorganic phosphorus (TIP) and total suspended solid (TSS) concentrations (mg l^{-1}) within each wetland and in wetland effluent beginning July 2010. Monthly grab samples were taken from each wetland, stored on ice, and transported to the lab. Additionally, we installed storm water samplers at the water control structure of each wetland. These samplers are designed to take a effluent sample when precipitation was significant enough to produce wetland discharged. We monitored weather data and river gaging station data and retrieved storm samples within 48 hours. An agriculture field adjacent to each wetland was also sampled for effluent water quality and grab samples were taken when significant flooding occurred on the field to warrant a water sample. Within 24 hours of sampling, aliquots of each sample were filtered through a 0.45 µm cellulose filter and NO_3-N, NO_2-N, NH_3-N, and DIP concentrations were determined colorimetrically on a Hach DR 5000 spectrophotomer according to appropriate protocols (APHA 2005). We digested unfiltered aliquots of each sample and determined TIP colorimetrically. We then estimated PP as the difference between TIP and DIP. Beginning in December 2010, in cooperation with the Water Quality Laboratory in the Department of Wildlife, Fisheries, and Aquaculture, we also determined NO_3-N and NO_2-N concentrations with a Lachat QuickChem 8500 Flow Injection Analysis System. We estimated TSS concentrations by filtering a known volume of sample through a pre-washed and dried 1.5-µm glass fiber filter. We then dried the sample-washed filter to a constant weight at 120 C. The difference in weight between the clean filter and the sample-washed filter was used to estimate the concentration of suspended solids in the sample.

RESULTS

In 2010, we harvested a total of 94 kg of crayfish from 2,005 trap sets in wetlands located in Arkansas, Mississippi, and Louisiana. Average daily yield was 2.18 kg ha^{-1} (CV = 30%). Wetlands located in Louisiana typically exhibited greater yields (Table 1). Additionally, two wetlands (Tippo [NMS2] and Wapanocca National Wildlife Refuge [AR4]) exhibited yields much greater than all other wetlands included in this study.

Consistent with yield, catch per unit effort was greater in Louisiana wetlands (Figure 1). We encountered two crayfish species of commercial importance, the red swamp crayfish (*Procambarus clarkii*) and the white river crayfish (*Procambarus acutus acutus*). Whereas spatial variation in size (based on carapace length) of white river crayfish was not apparent (Figure 2), red swamp crayfish were significantly larger from Louisiana wetlands (Kruskal Wallis $p < 0.0001$; Figure 3). As with yield, it appears that a spatial gradient in crayfish size and possible growth occurs in moist-soil wetlands in the MAV. Whereas the mechanism for this phenomena in crayfish is unknown, extended growing seasons in lower latitudes likely results in larger size crayfish as in other aquatic populations (Garvey and Marschall 2003).

Significant drought conditions existed when we installed water monitoring stations. The first significant storm event that created runoff from wetlands occurred in late November 2010. We collected grab and storm effluent samples from wetlands and adjacent agriculture fields. In effluent samples, TIP and PP concentrations were always greater in agriculture discharge, whereas DIP (i.e., fraction of inorganic phosphorus not bound to sediments) was comparably high in discharge from wetlands and agriculture fields (Figure 4). Greater PP concentrations in agriculture fields were likely caused by greater discharge concentrations of TSS from these fields. Conversely, concentrations of NO_2-N and NH_4-N were greater in effluent from wetlands compared to agriculture fields during storm events. Concentrations of NO_3-N were always greater in agriculture fields. Storm events did not cause increases in concentrations of NO_3-N in wetland effluent compared to grab samples when discharge was not occurring. Concentrations of PP and TSS were similar in effluent and grab samples from wetlands.

DISCUSSION

In high yield ricefield crayfish production systems in Louisiana, producers can expect daily yields of 10.5 kg ha^{-1}. Our yields from 2009 and 2010 were substantially lower from moist-soil wetlands. Whereas yields are greater in traditional rice production fields, these systems also have greater associated fixed and variable costs compared to moist-soil wetlands (Avery et al. 1998). For example, a producer with a 16-ha rice field can expect to spend $1,000 to $2,000 annually on planting a forage base in fields. This variable cost is nonexistent in moist-soil wetlands because the forage base is natural vegetation. Additionally, a crayfish producer in Louisiana must produce high yields to profit. An estimate of the expected direct costs associated with rice-crayfish operations is $750 ha^{-1} (Avery and Lorio 1999). Preliminary estimates of direct costs associated with harvesting crayfish from moist-soil wetlands is \$485 ha^{-1}. These direct costs include one-time costs associated with purchasing traps; annual direct costs can be reduced after the first year of harvest. Therefore, producers of crayfish in rice-crayfish operations must either sell more crayfish or demand higher prices to cover direct costs.

Seasonally flooded plant communities concentrate nutrients and sediments from agricultural and other non-point sources of run-off (Maul and Cooper 2000, Manley et al. 2009). With data collected since July 2010, we have demonstrated that concentrations of nutrients and sediments, with the exception of NO_2-N and NH_3-N in water discharged from moist-soil wetlands, are comparably less than in water discharged from agriculture fields during fall-winter. Greater concentrations of ammonium in wetlands likely were caused by ammonification of organic matter being decomposed. Agriculture fields have little crop cover after harvest and therefore little organic material is available for decomposition. However, from a nutrient reduction viewpoint, the lower concentrations of NO_3-N in wetlands are of more importance. Agriculture-fertilizer derived NO_3-N has been linked to eutrophication of receiving waterbodies. A major environmental, ecological, and economic consequence of loss of wetlands throughout the Mississippi River Basin has been the development of the hypoxic zone in the Gulf of Mexico (Rabalais et al. 2002). Thus, moist-soil wetlands may reduce nitrogen inputs to the Gulf of Mexico.

Although we estimated greater concentrations of DIP from wetlands compared to agriculture fields, greater PP concentrations in agriculture field effluent is more problematic. Whereas DIP is readily available for uptake by plants, PP is bound to sediments and minerals and therefore its availability is limited. Phosphorus bound to sediments can easily dissociate causing internal nutrient loading and can also be transported to receiving systems. Therefore, greater concentrations of sediment-bound phosphorus can increase the dissolved phosphorus concentrations to the point of eutrophication in freshwater systems. Whereas relative comparisons of concentrations of nutrient and pollutants are useful in characterizing the effect of habitat type and storm events on water quality, estimating total loads discharged from these systems will quantify the importance of wetlands in agriculture landscapes. We will continue to monitor water quality in effluent from wetlands and agriculture fields through 2011 and combine these data with calculated discharge volumes for storm events to quantify annual loads (kg) of pollutants.

Strategic location of moist-soil wetlands amid farmed lands can reduce transport of sediments and other nutrients into surrounding watersheds and thus enhance water and environmental qualities. Quantifying ecosystem services provided by moist-soil management will facilitate fulfillment of proposed surface water quality regulations (i.e., total maximum daily loads). Finally, understanding the economic benefits of crayfish harvests from moist-soil wetlands will likely encourage establishment and management of these wetlands and therefore increase habitat for waterfowl and other wetland wildlife throughout the MAV.

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PUBLICATIONS AND PRESENTATIONS

Spencer, A.B. 2010. Crayfish harvest potential from reclaimed catfish ponds. Natural Resources Enterprises workshop, Stoneville, Mississippi. June 16, 2010.

Spencer, A. B., R. M. Kaminski, L. D'Abramo, and J. Avery. 2010. Crayfish harvest: An ancillary ecosystem service provided by moist-soil management. Oral Presentation. Presented at the International Association of Astacology, Columbia, Missouri, July 18-23, 2010.

Spencer, A.B., R.M. Kaminski, J.L. Avery, L. D'Abramo, R. Kröger. 2010. Ancillary ecosystem services from moist-soil wetlands. Mississippi Water Resources Conference, Bay St. Louis, MS.

Spencer, A.B., R.M. Kaminski, J.L. Avery, L. D'Abramo, R. Kröger. 2010. Ancillary ecosystem services from moist-soil wetlands. Presented to Wetlands and Waterfowl students from University of Tennessee, Starkville, MS.

Alford, A.B., R.M. Kaminski, R. Kroger. 2011. Water quality of effluent from managed wetlands in an agriculture landscape. Poster Presentation. Southeastern Natural Resources Graduate Student Symposium, Starkville, MS.

AWARDS

Spencer, A.B. 2010. Best Student Presentation Award. Mississippi Water Resources Conference, Bay St. Louis, MS.

TRAINING POTENTIAL AND INFORMATION TRANSFER

The proposed project provided necessary field and laboratory research for Amy Alford, a Ph.D. student in Department of Wildlife, Fisheries and Aquaculture (WFA), Mississippi State University. Mrs. Alford's field of interest is wetland ecology and aquatic ecosystem management. She also holds a M.S. degree in fisheries from the Department and her extensive aquatic ecology and population modeling background will aid in the successful implementation of the proposed research. We hired Mason Conley, an undergraduate student in the Department to help with the extensive field work. Numerous graduate students in the Department also volunteered invaluable time.

We also encouraged landowners and land managers to observe water quality and crayfish sampling activities. We received field assistance from one landowner. We also involved high school students in crayfish harvest activities during the College of Forest Resources' sponsored summer camp. Mrs. Alford and Mr. Conley also participated in a Natural Resources Enterprises sponsored workshop in Stoneville, MS where they met with area landowners to discuss the potential for crayfish harvest from wetlands managed for wildlife habitat. We believe that continuing our model of a combination of formal and informal training will increase the population of individuals aware of wetland conservation principles.

STUDENT TRAINING

Name	Level	Major
Amy B. Alford (Co-PI)	Ph.D.	Forest Resources
Mason Conley (Wage)	B.S.	WFA
John Perron (Wage)	B.S.	WFA
Kelsey Brock (Wage)	B.S.	Speech Pathology
Candice Bogen	B.S.	WFA
Matt Palumbo (Volunteer)	M.S.	WFA
James Callicutt (Volunteer)	M.S.	WFA

SIGNIFICANT RESEARCH FINDINGS

We completed the second year of our proposed three-year research designed to quantify crayfish harvest and effluent water quality parameters as ecosystem services provided by moist-soil management. In 2009, we estimated daily yield of crayfish from moist-soil wetlands in Mississippi was 1.75 kg ha^{-1} (CV = 16%, n = 9). With 2010 fiscal year project funds, we were able to expand our sampling efforts to include wetlands in Arkansas, Louisiana, and Mississippi. In 2010, we estimated daily yield of crayfish from these wetlands to be 2.18 kg ha^{-1} (CV = 30%, n = 15). Whereas these yields are less than that expected from high production culture systems in Louisiana (i.e., 10 kg ha^{-1}) we estimate that reduced annual fixed costs associated with moist-soil wetland management compared to rice field management may offset lower yields. Additionally, we found that crayfish yields and sizes increased in Louisiana wetlands compared to wetlands in the northern MAV. Although these data represent only the second of three years of research, we suspect that higher yields in southern latitudes may warrant region-specific estimates of yield and economic return of crayfish harvests.

We began monitoring water quality of wetland effluent in July 2010. Whereas other research has demonstrated water quality within wetlands is characterized by lower concentrations of nutrients and sediments compared to agriculture fields, no attempt has been made to describe and compare water quality that is delivered to receiving waterbodies from these habitats. Therefore, we installed effluent sampling stations at 5 wetlands and 5 adjacent agriculture fields in the north Delta region of Mississippi. From November 2010 to April 2011 we have collected storm and grab samples from each of these sites. We demonstrated that during high runfoff events after storms, concentrations of NO_3-N and TIP were less in wetland effluent compared to agricultural effluent. Additionally, storm events only increased concentrations of NO_2-N and NH_3-N in wetland effluent compared to concentrations of these nutrients within wetlands during non-runoff periods. Whereas the mechanisms of nutrient and sediment retention in these systems is beyond the scope of this research, it is evident that runoff events are not causing great losses of nutrients from moist-soil wetlands as was seen in agriculture fields.

FUTURE RESEARCH

This report summarizes the results of the second year of our three-year research project. We began the third year of crayfish harvest from moist-soil wetlands in April 2011. We have expanded our sampling efforts to include wetlands in the northern region of the MAV in the Missouri Bootheel. We continue to monitor water quality of wetland and agriculture effluent at our monitoring stations located in the north Delta of Mississippi. We have installed water level loggers at each of these locations are collecting data necessary for us to calculate discharge from these habitats. With these data, we will then be able to calculate annual loads (kg) of nutrients and sediments exported by wetlands. We expect that water quality monitoring efforts will continue through Winter 2011-2012. We received additional support from Ducks Unlimited, Inc. to conduct a consumer acceptability trial of crayfish harvested from moist-soil wetlands. We will be conducting the trial in May 2011 at the Garrison Sensory Laboratory. The objective of the trial is to determine if variation occurs in the acceptability (e.g., in flavor and appearance) of tail meat of crayfish harvested from moist-soil wetlands compared to crayfish harvested in commercial ponds. The acceptability of the product is necessary in order to market moist-soil crayfish as an alternative source of income for landowners.

Table 1. Crayfish harvest statistics from 15 moist-soil wetlands in the Mississippi Alluvial Valley and Interior Flatwoods April-June 2010.

Site	Site Identifier	Average harvest (kg/ha/day)
Cache River NWR unit 6	AR1	0.26
Cache River NWR unit 9	AR2	0.85
Wapanocca NWR unit 1	AR3	0.05
Wapanocca NWR Woody Pond	AR4	7.22
Coldwater NWR unit S	NMS1	0.70
Tippo WRP	NMS2	9.13
Morgan Brake NWR	SMS1	0.45
Panther Swamp NWR	SMS2	1.22
Yazoo NWR Cox Pond	SMS3	1.34
Tensas NWR Ezell Tract	LA1	2.23
Catahoula NWR unit 1	LA2	1.67
Catahoula NWR unit 2	LA3	1.95
Grand Cote NWR	LA4	2.36
Young WRP	EMS1	2.00
Noxubee NWR unit 2	EMS2	1.05

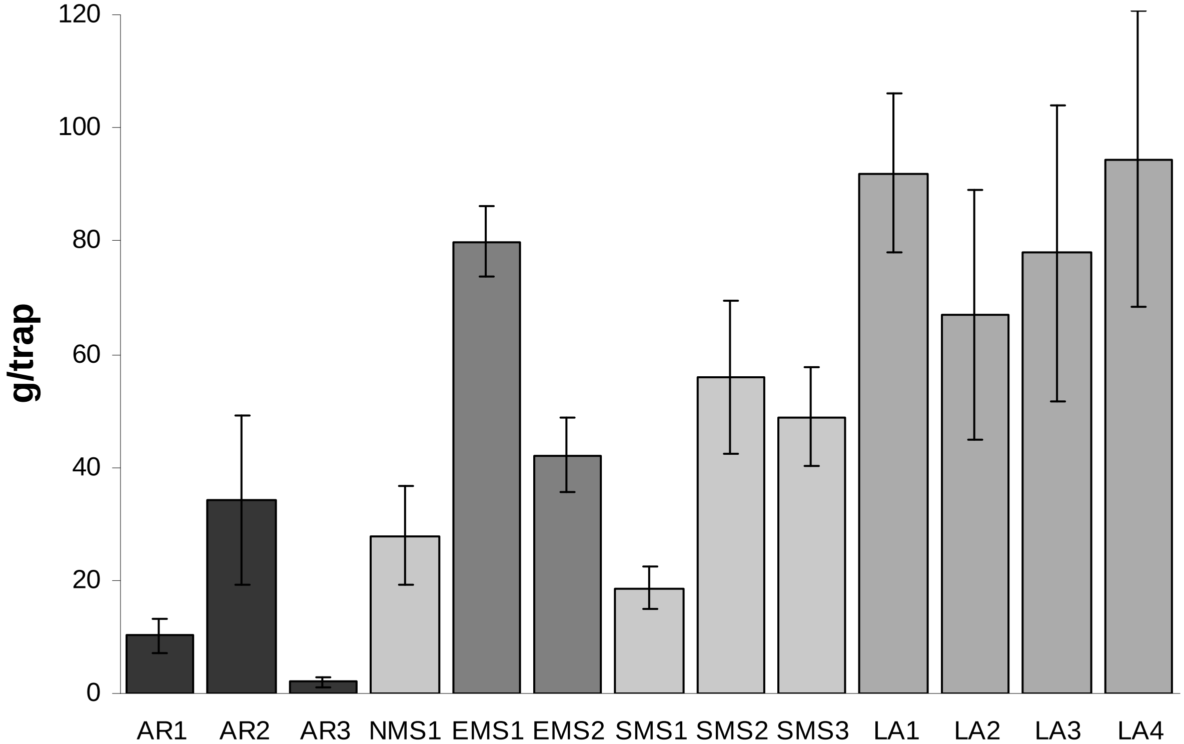

Figure 1. Catch per unit effort (grams per trap set) of crayfish harvested from moist-soil wetlands in the MAV and Interior Flatwoods April-June 2010. Wetlands AR4 and NMS2 exhibited unusually high catch rates and are excluded. Error bars represent standard error.

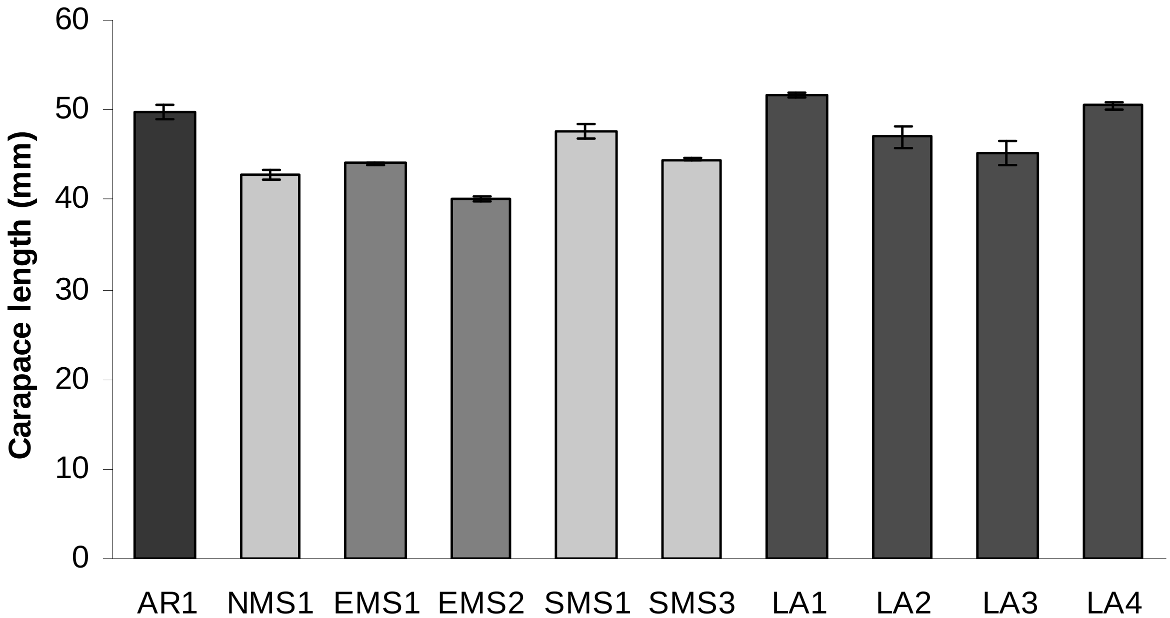

Figure 2. Average carapace length of white river crayfish *Procambarus acutus acutus* harvested from moist-soil wetlands in the MAV and Interior Flatwoods April-June 2010. Error bars represent standard error.

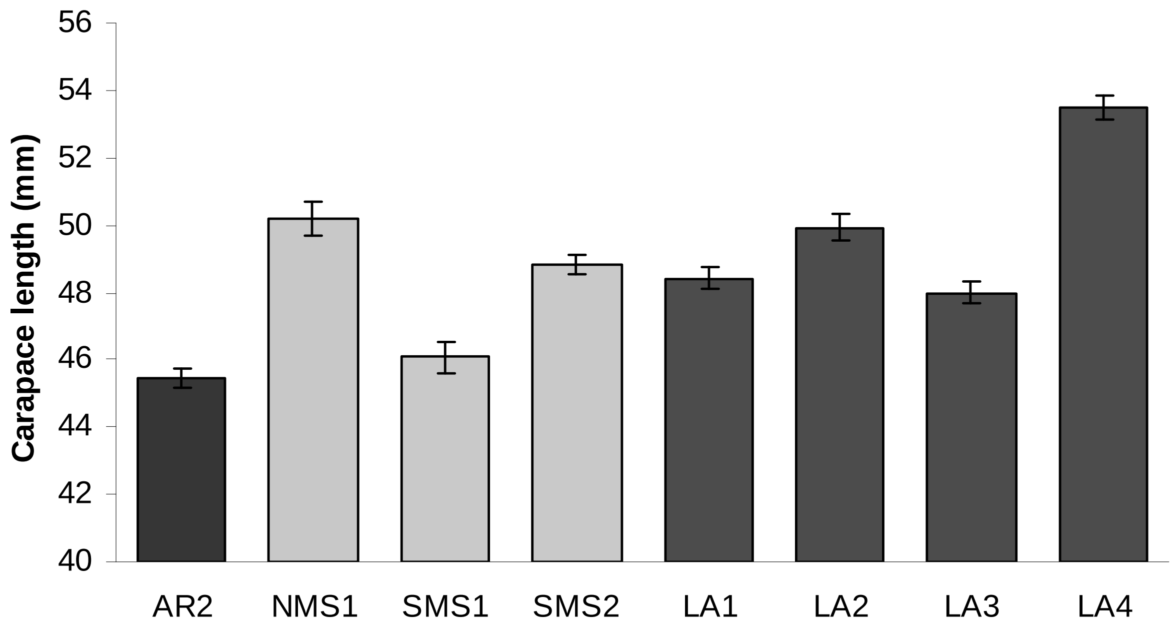

Figure 3. Average carapace length of red swamp crayfish *Procambarus clarkii* harvested from moist-soil wetlands in the MAV April-June 2010. Error bars represent standard error.

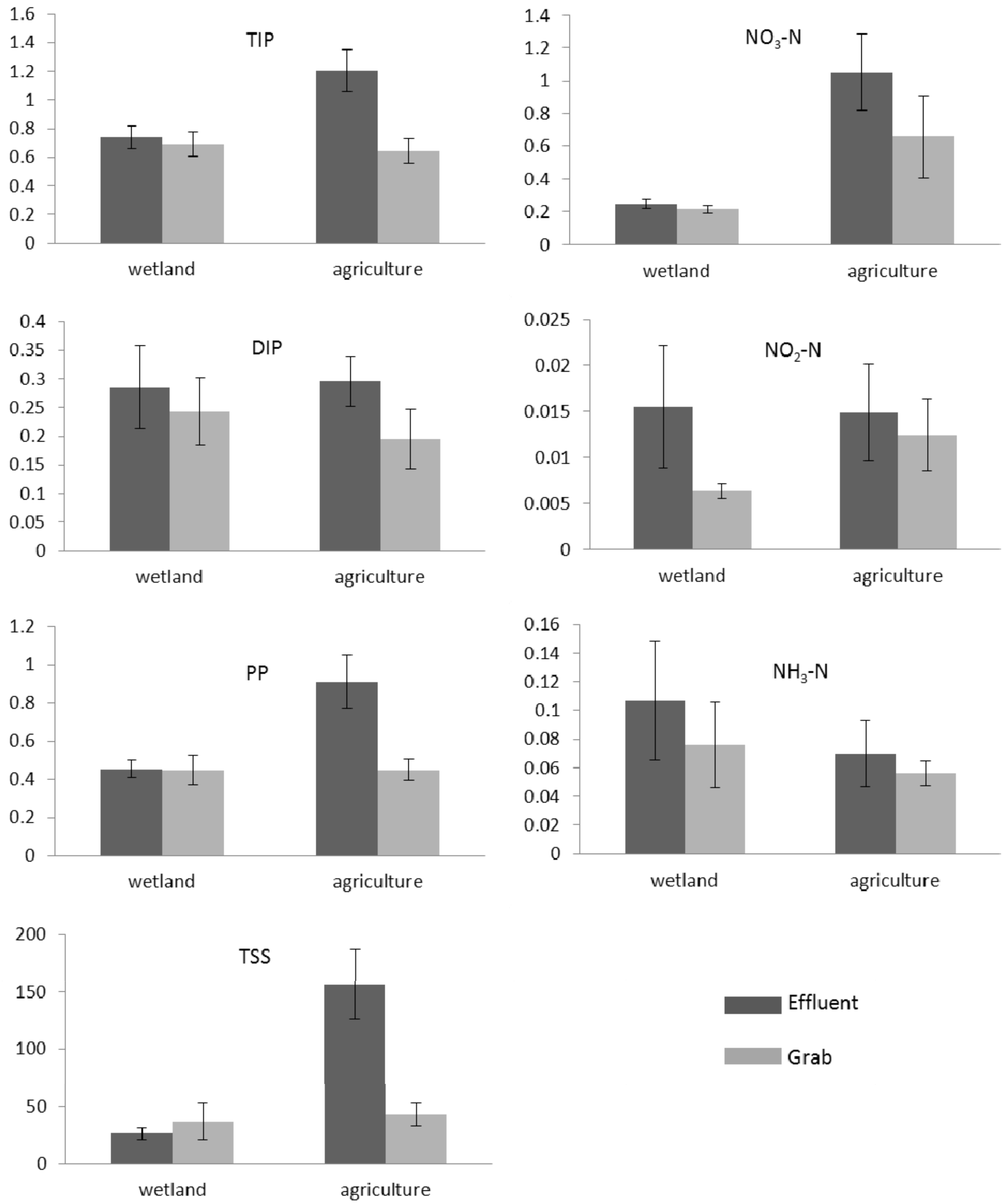

Figure 4. Average concentrations (mg l^{-1}) of nutrients and sediments estimated from effluent and grab samples taken from 5 wetlands and 5 agriculture fields in Mississippi November-April 2011. Error bars represent standard error.

Water-Conserving Irrigation Systems for Furrow and Flood Irrigated Crops in the Mississippi Delta

Basic Information

Title:	Water-Conserving Irrigation Systems for Furrow and Flood Irrigated Crops in the Mississippi Delta
Project Number:	2010MS112B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3rd
Research Category:	Engineering
Focus Category:	Irrigation, Water Quantity, Non Point Pollution
Descriptors:	None
Principal Investigators:	Joseph H. Massey

Publications

1. Quarterly reports 2010-2011 submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Massey, J., Earth Day Week talk at Mississippi State University, Water and Agriculture in the Mississippi Delta, April 19, 2010, Mississippi State, MS.
3. Massey, J., Reducing Water Use in Mississippi Rice Production: Opportunities and Challenges presented at the Yazoo-Mississippi Delta Joint Water Management District Board of Directors Meeting, April 21, 2010, Leland, MS.
4. Massey, J., Management of Risk and Agricultural Resources in the 21st Century presented at the Professional Soil Classifiers Association of Mississippi, July 15, 2010, Crystal Springs, MS.
5. Massey, J., Agriculture and the Mississippi Delta presented at the Plant & Soil Sciences Departmental Seminar, October 4, 2010, Mississippi State, MS.
6. Massey, J., Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta presented at the 2010 Mississippi Water Resources Conference, November 3-5, 2010, Bay St. Louis, MS.
7. Massey, J., Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta status report presented to the Mississippi Water Resources Research Institute Advisory Board, November 9, 2010, Mississippi State, MS.
8. Massey, J., Efficient Irrigation Systems Overview presented at the Yazoo-Mississippi Delta Joint Water Management District November 10, 2010, Stoneville, MS.
9. Massey, J., 2011, Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta in the 2010 Mississippi Water Resources Conference Proceedings, p. 141, http://www.wrri.msstate.edu/pdf/2010_wrri_proceedings.pdf.
10. Massey, J., 2011, Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 14 pgs.

Mississippi Water Resources Research Institute (MWRRI)
Final Project Report

Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta

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Abstract

The goal of this project was to improve irrigation water- and energy-use efficiency for one of the most economically important cropping rotations practiced in the Mississippi delta, the soybean-rice rotation. Combined economic activity for the two crops in the delta exceeds $600 million annually while combined irrigation water use approaches 2 million A-ft per season. As a result, a modest reduction in the amount of irrigation water used in the soybean-rice rotation could help reduce the current overdraft of the alluvial aquifer. Results from these 2010 on-farm trials indicate soybean irrigation savings using NRCS Phaucet optimization software ranged from 6 to 18% compared to non-optimized furrow irrigation while associated energy use reductions ranged from 32 to 20%, respectively. (It is important to note that in order to foster comparison, the soybean fields used in these studies were rectangular in shape; water savings are expected to be greater for more irregular (i.e., hard to irrigate) soybean fields.) Irrigation water used in rice grown using straight-levees with multiple inlets and intermittent flood management averaged 23.1 ± 2.4 A-in/A as compared to 32.4 A-in/A for straight-levee rice using multiple inlets without intermittent flood management. These results indicate that by overlaying an intermittent flood regime on practices that are already familiar to rice producers in Mississippi, rainfall capture is increased and over-pumping is decreased such that overall water use is reduced by ~40% over the standard rice irrigation practices. Field trials comparing rough rice yield and milling quality for 15 rice varieties grown on two soil series indicated that commercial rice varieties, grown using standard fertility and pest control programs, well-tolerated a carefully-controlled intermittent flooding regime. Each inch of water not pumped from the Alluvial aquifer onto an acre of rice or soybean saves the energy equivalent of ~0.7 gallon diesel fuel (with concomitant reduction in CO_2 emissions by ~200 lbs/A). Assuming a current off-road diesel price of $3.20/gallon, a 9 acre-inch (40%) reduction in rice irrigation translates to a savings of ~$20 per acre while a 1.5 acre-inch (18%) reduction in soybean irrigation represents a savings of ~$3 per acre. By reducing irrigation water and associated energy inputs in soybean and rice production, the producer reduces input costs while reliving pressure on the Alluvial aquifer and also reduces carbon emissions.

Critical Water Problem Addressed

The current rate of groundwater extraction from the Alluvial aquifer in the Grand Prairie region of Arkansas is unsustainable. Declines in groundwater availability are expected to reduce the region's crop production in coming years (1, 2). As a result, some producers have begun tapping into the underlying Sparta-Memphis aquifer for irrigation supplies. This is of great concern to cities such as Memphis (3) because the Sparta-Memphis aquifer is used primarily for domestic purposes and is not as productive as the Alluvial aquifer. The costly and controversial Grand Prairie Area Demonstration Project (4, 5) is being constructed to partially compensate for the region's anticipated loss in irrigation capacity.

The Mississippi delta is also experiencing groundwater decline, although less severe than that occurring in Arkansas (Figure 1). The decline in Mississippi has caught the attention of state regulators who have clearly indicated that water quantity, and the prevention of groundwater depletion in the Delta, are both important to the economic future of Mississippi (6).

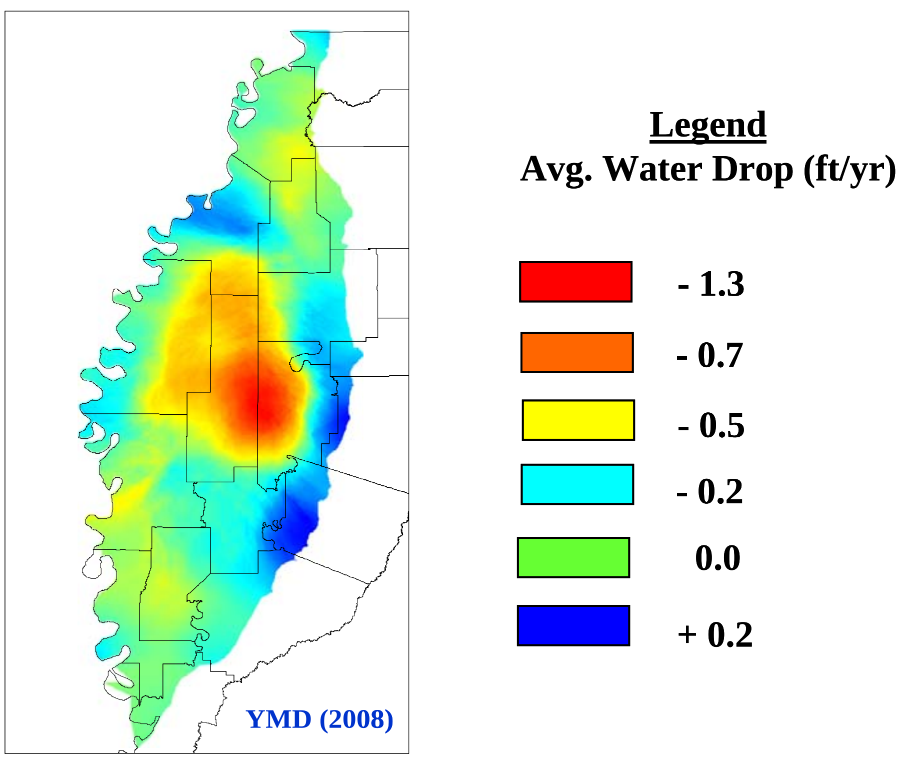

Figure 1. Average 20-yr decline in depth of alluvial aquifer in

Research Scope and Related Research

The 2:1 soybean-rice crop rotation is a three year rotation practiced on nearly one million acres across the Mississippi delta (Figure 2). This rotation has a combined economic activity that exceeds $600 million annually and uses approximately 2 million A-ft of irrigation water per season (Table 1). Thus, a modest reduction in the amount of irrigation water used in the soybean-rice rotation could help to reduce overdraft of the alluvial aquifer.

Table 1. Estimated water use in Mississippi agriculture (7, 8).

Crop	2009 Acres (thousands)	Avg. H_2O Use (Ac-ft/Ac)	Seasonal Water Use (Ac-ft)
Rice	250*	3	750,000
Corn	900	0.8	720,000
Soybeans	2,500* (Delta only: 1,750)	0.7	1,750,000 (Delta only: 1,225,000)
Cotton	270	0.5	135,000
Fish	70	1.9	133,000

* 100% of the rice and ~70% of the soybeans grown in MS occur in the Mississippi delta.

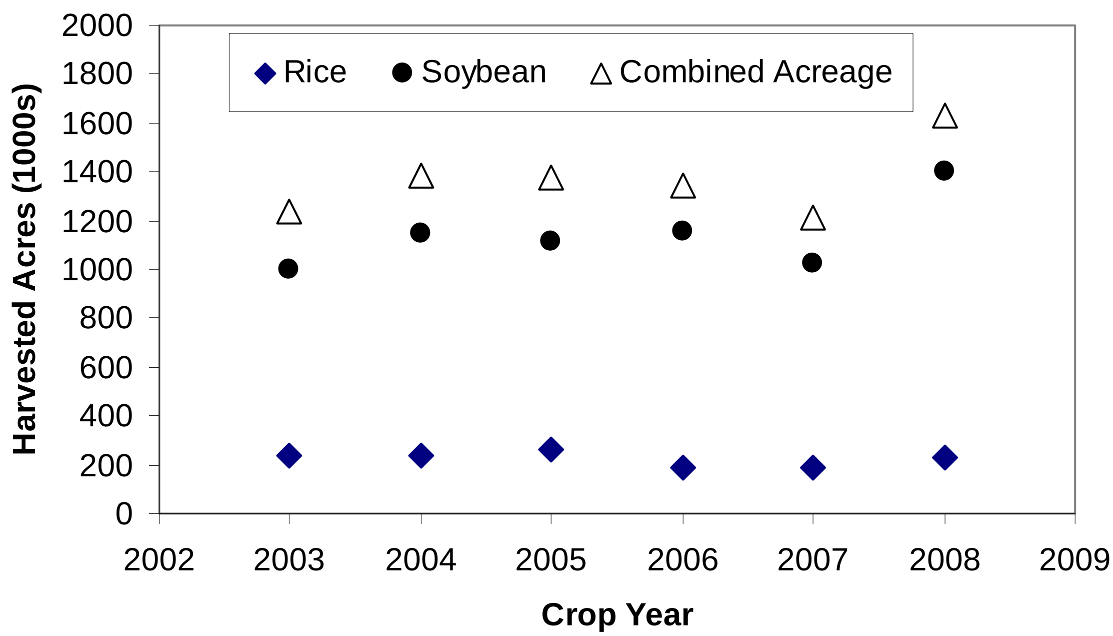

Figure 2. Rice and soybean acreages in the Mississippi Delta (2003-2008). (8).

Soybean (*Glycine max*) are often grown on beds and irrigated using lay-flat plastic tubing (Figure 3). The USDA NRCS *Phaucet* irrigation computer program[1] optimizes hole size and number in plastic tubing, improving irrigation efficiency by 25% or more according to research conducted in Arkansas(9). Phaucet requires that the overall field dimensions (row lengths and widths) and slope of the field (total head pressure, in feet) and flow rate of the irrigation pump (gallons per minute) be determined. Coupling this information with the dimensions of the plastic tubing, the program provides the optimal hole sizes and numbers to distribute water more evenly across irregularly-shaped fields.

Figure 3. Irrigation using lay-flat tubing can be improved using the NRCS Phaucet program that determines optimal hole size and number for furrow-irrigated crops.

For rice (*Oryza sativa*), this project will build upon research conducted at Mississippi State University (10) that has found that coupling multiple-inlet (MI) irrigation with intermittent (Int) flood management may reduce water use by as much as 50% relative to conventional irrigation practices. Unlike conventional flooding where the rice flood is maintained at a nearly constant depth throughout the growing season, intermittent irrigation allows the flood to naturally cycle over time (Figure 5-a). This reduces water use by (a) reducing over-pumping and associated tail-water runoff, and (b) by increasing rainfall capture. The Mississippi delta receives approximately 10 to 14-inches per season. In practice, as many as 8 drying cycles have been achieved by Mississippi rice growers, resulting in paddies being maintained at "less-than-full" throughout the entire growing season (Figure 5-b), and significantly improving rainfall capture. Rice yield and grain milling quality have been unchanged relative to that of control fields. Moreover, farmers have found that simple depth gauges installed in their rice paddies (Figure 6) and spring-wound timers (Figure 7) can aid in managing the rice flood.

[1] NRCS Phaucet program available at link: (http://www.wsi.nrcs.usda.gov/products/w2q/water_mgt/irrigation/irrig-mgt-models.html)

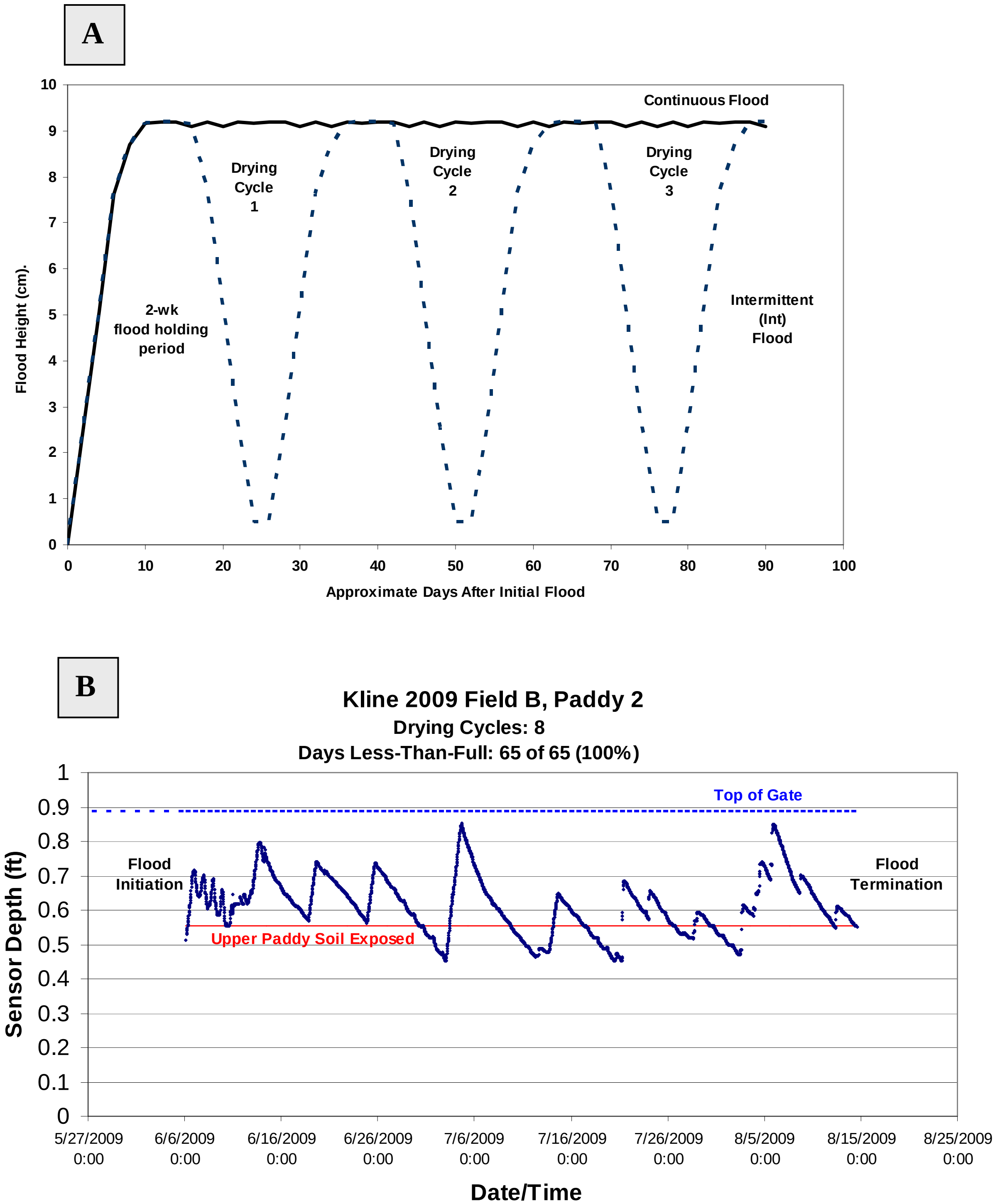

Figure 5. Diagram demonstrating flood depths in rice paddies maintained using continuous or intermittent flooding (A), and actual flood management that resulted in 8 drying cycles and 100% of days where paddy was maintained at a 'less-than-full' status (B). The water use in Field B was 1.22 Ac-ft/A.

Figure 6. Low-cost depth gauges may assist in the careful management of rice flood.

Figure 7. Manual timers installed to control irrigation pumps can save additional water and energy in soybean and rice production.

Objectives

The overall goal of this project was to collaborate with producers to develop water-conserving irrigation practices for soybean and rice so as to reduce overall withdrawals from the alluvial aquifer while also reducing input costs related to irrigation. To reach this goal, the following objectives were pursued:

<u>Objective 1</u>: Compare season-long water and energy use, grain yield, and grain quality for soybean grown using furrow irrigation systems optimized using the NRCS Phaucet and pump timers to that of non-optimized furrow irrigated soybean.

<u>Objective 2</u>: Compare season-long water and energy use, grain yield, and grain quality for rice grown using intermittent flood plus multiple inlet irrigation, pump timers, and depth gauges to rice grown using only multiple inlet irrigation.

<u>Objective 3</u>: Using input from producers and crop consultants, refine approaches developed in Objectives 1 and 2 to create systems that can be readily adopted across the delta.

Research Design

Soybean

Ten fields at five commercial farms located in Bolivar, Leflore, and Washington counties were fitted with McCrometer flowmeters for season-long water use and arranged to allow side-by-side comparisons of water and energy use with and without *Phaucet* furrow irrigation optimization.

Rice

Twelve fields at four commercial farms located in Bolivar, Coahoma, and Leflore counties were fitted with McCrometer flowmeters for season-long water use and Global Water depth loggers for determining flooding pattern. The water use and flood management practices were monitored from flood initiation (~mid-May) to flood termination (~mid-August). Weather stations and/or electronic tipping bucket rain gauges were installed at each producer site.

Two variety trials were conducted in Bolivar County to determine the effects of variety, soil type, and intermittent flooding on rice yield and milling quality. Fifteen rice varieties using four replications each were planted in the top and bottom of a paddy near the top of a field. The top of the paddy underwent intermittent flooding while the bottom of the paddy was to remain continuously flooded. This allowed direct comparison of the effect of intermittent flooding on rice yield and milling quality. This study was conducted on a clay and silt loam soil.

Data Collection and Analysis

Seasonal water use (A-ft/A), water depth profile (rice only), electrical energy use (soybean), grain yield (bu/A), and milling quality (rice only) were collected for each field included in the study. Simple descriptive statistics were used to report these values.

Results and Benefits

Soybean

Owing to circumstances beyond our control, side-by-side field comparisons of conventional furrow irrigation versus furrow irrigation optimized using the NRCS *Phaucet* program were made at only two farm locations in Washington Co. At one location, *Phaucet* reduced water use by approximately 18% (15.6 vs. 13.3 A-in/A) and energy use by approximately 20% (313 vs. 260 gallons per 29 A fields). At the second location, water used was reduce by only 6% (20.3 vs. 19.1 A-in/A), but energy use was reduced by ~32% (3202 vs. 2431 kWh). This latter result reflects that overall water use was not significantly different, but the total run time for the pump was less as the *Phaucet* optimization program allowed the water to distribute across the field in a more efficient manner, saving considerable energy. Soybean yields at both locations were not significantly different between irrigation treatments. These results are summarized in Table 2.

Table 2. Results from two soybean irrigation trials comparing water and energy use with and without Phaucet furrow irrigation optimization.

Parameter	Conventional Design	Phaucet Design	Savings (%)
Trial A Field Size (A)	16	15	
Water Use (A-in/A)	20	19	5
No. of Irrigations	5	6	---
Energy Use (kWh/A)	200	162	23
Total Pumping Time (hrs)	153	116	32
Soybean Yield (bu/A)	62.2	62.2	---
Trial B Field Size (A)	29	30	
Water Use (A-in/A)	16	13	23
No. of Irrigations	3	3	---
Energy Use (kWh/A)	11	9	22
Total Pumping Time (hrs)	123	105	17
Soybean Yield (bu/A)	48.2	48.6	---

Rice

Irrigation water used in rice grown using straight-levees with multiple inlets and intermittent flood management averaged 23.1 ± 2.4 A-in/A as compared to 32.4 A-in/A for straight-levee rice using multiple inlets without intermittent flood management. These results indicate that by overlaying an intermittent flood regime on practices that are already familiar to rice producers in Mississippi, rainfall capture is increased and over-pumping is decreased such that overall water use was reduced by ~40% over the standard rice irrigation practices. These results are summarized in Table 3.

Table 3. Summary of rice irrigation results for 2010 at various field locations.

Field Location	Field Size (A)	Soil Type	Irrigation System	Irrigation Added (A-in/A)
Coahoma Co.	32	clay	SL + MI + Int.	19.3
	30	clay	SL + MI + Int.	26.9
Bolivar Co.	34	clay	SL + MI + Int.	22.9
	73	clay	SL + MI + Int.	23.2
	64	clay	SL + MI + Int.	29.3*
	36	clay	SL + Conv. Flood	29.9
	35	clay	SL + MI + Int.	23.2
Leflore Co.	40	clay	SL + MI	23.3
	40	clay	SL + MI	28.8
	40	clay	SL + MI	27.8

(*) water use increased owing to field having lost its precision level, necessitating the need to keep flood depth higher in middle sections of field with the result of increased runoff.

In the rice variety trials conducted on the clay soil, the top-of-the-paddy treatments underwent five wetting-drying cycles while the bottom plots remained flooded except for two wetting-drying cycles. Water use on this field was approximately 23 A-in/A irrigation water as compared to the delta-wide average of 32 A-in/A for straight-levee with side inlets (YMD, 2010). Pair wise comparisons (top vs. bottom paddy) for each variety suggests that yields (Table 4) and milling quality (data not shown) of the different rice varieties were unaffected by these wetting-drying cycles, except for 6004 where top of the paddy yield was higher than that of the bottom paddy ($p = 0.0326$). When analyzed across all varieties, the statistics indicated that there significant (~5%) increase in yield ($p< 0.05$) in favor of the intermittent (top of paddy) plots. It has been reported that rice grown under intermittent irrigation often yields higher than when it is continuously flooded (11).

In the rice variety trials conducted on the silt loam soil, the producer had difficulty keeping this field irrigated due to recent sub-soiling, dry weather, and weak irrigation well. As a result, the top of paddy plots underwent 10 wetting-drying cycles and the bottom underwent 8 cycles. Water use on this field was nearly 6 A-ft/A, reflecting the harsh conditions of this test. Thus, this test does not realistically allow for valid comparisons of intermittent flood impacts on yield and milling because both top and bottom plots underwent wetting-drying cycles. As shown in Table 5, pair wise comparisons of top vs. bottom paddy yields were not different ($p > 0.05$) except for CL181 ($p = 0.0123$) which had higher yield for the bottom paddy plot as compared to the top plots. Similar results were observed for milling quality whereby no differences ($p > 0.05$) between top and bottom plots were detected (data not shown).

Significant Research Findings

These data support the premise that readily-available technologies and management strategies such as the NRCS *Phaucet* furrow irrigation optimization program, improved crop genetics, pump timers, flood depth gauges, and intermittent irrigation practices can be combined within cropping rotations to significantly reduce water and energy use while maintaining economically-viable yields. Each inch of water not pumped from the Alluvial aquifer onto an acre of rice or soybean saves the energy equivalent of ~0.7 gallon diesel fuel and reduces CO_2 emissions by ~200 lbs per A. Given a current off-road diesel price of $3.20/gallon, the 9 acre-inch (40%) reduction in rice irrigation demonstrated in this study translates to a savings of ~$20 per acre while a 1.5 acre-inch (18%) reduction in soybean irrigation represents a savings of ~$3 per acre. By reducing irrigation water and associated energy inputs in the soybean-rice rotation, the producer can reduce input costs, relieve pressure on the Alluvial aquifer, and also reduce carbon emissions.

Table 4. P-values for comparison of yields at top versus bottom paddy on clay soil.

	Avg. Rice Yield (lb/A) dry		
Variety	**Top of Paddy (int flood)**	**Bottom of Paddy (cont flood)**	**Type III Pr > F***
6004	10,548	9,067	**0.0326**
Bowman	9,838	9,905	0.9004
CL111	10,850	11,380	0.5048
CL131	9,142	9,762	0.2304
CL142	11,605	10,489	0.0643
CL151	11,428	10,852	0.2763
CL181	9,588	9,278	0.6637
CLX745	12,386	11,698	0.1889
Cheniere	10,576	10,124	0.1017
Cocodrie	10,796	10,528	0.2154
Neptune	10,396	9,452	0.0756
Rex	10,481	9,899	0.1846
Taggart	11,486	10,961	0.3535
Templeton	11,083	9,933	0.0618
XL723	12,809	12,808	0.9986

(*)Values less than 0.05 indicate difference in yield between top and bottom of paddy for that variety.

Table 5. P-values for comparison of yields at top versus bottom paddy on silt loam soil.

	Avg. Rice Yield (bu/A) dry		
Variety	**Top of Paddy (int flood)**	**Bottom of Paddy (cont flood)**	**Type III Pr > F***
6004	8,108	8,697	0.3636
Bowman	7,578	7,139	0.5650
CL111	9,637	10,398	0.1592
CL131	7,986	8,522	0.1948
CL142	9,084	9,482	0.7100
CL151	7,957	8,815	0.2325
CL181	8,033	8,759	**0.0123**
CLX745	13,506	13,981	0.3847
Cheniere	7,697	8,173	0.0857
Cocodrie	8,846	9,085	0.5360
Neptune	8,651	9,633	0.3829
Rex	8,034	9,222	0.1178
Taggart	8,607	8,981	0.3871
Templeton	8,384	8,691	0.4008
XL723	12,445	13,788	0.0987

(*)Values less than 0.05 indicate difference in yield between top and bottom of paddy for that variety.

Technology and/or information transfer and dissemination

Presentations

Earth Day week talk MSU April 19, 2010. Water and Agriculture in the Mississippi Delta. Mississippi State, MS.

YMD Board of Directors Meeting.. Reducing Water Use in Mississippi Rice Production: Opportunities and Challenges. Leland, MS. 21 April 2010

Professional Soil Classifiers Association of Mississippi. Management of Risk and Agricultural Resources in the 21st Century. Crystal Springs, MS. 15 July 2010.

Agriculture and the Mississippi Delta. PSS Departmental Seminar, 04 Oct 2010. Mississippi State

University.

Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta. Mississippi Water Resources Research Institute Annual Conference, Bay St. Louis, MS. 03 November 2010.

Mississippi Water Resources Research Institute Advisory Board meeting. Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta status report. Mississippi State, MS. 9 November 2010.

Yazoo Water Management District Water Meeting. Efficient Irrigation Systems Overview. Stoneville, MS. 10 Nov 2010.

Training potential

To date, one undergraduate student was involved in this research.

Future research

Additional research that investigates technological advances in crop breeding and pump monitoring and irrigation system control electronics should be conducted to derive water- and energy-efficient production systems that provide the grower options and increased resilience for 21st century cropping conditions.

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A Climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta Shallow Alluvial Aquifer

Basic Information

Title:	A Climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta Shallow Alluvial Aquifer
Project Number:	2010MS113B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3rd
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Groundwater, Water Use
Descriptors:	None
Principal Investigators:	Charles Wax, Jonathan Woodrome Pote

Publications

1. Quarterly reports submitted 2010-2011 to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS.
2. Wax, C.L., A climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta shallow alluvial aquifer, presentation of preliminary results made to U.S. Army Corps of Engineers Climate Symposium, Vicksburg, MS, September, 2010.
3. Wax, C., J. Pote, R. Thornton, 2010, Refining effective precipitation estimates for a model simulating conservation of groundwater in the Mississippi Delta Shallow Alluvial Aquifer, oral presentation at the 2010 Mississippi Water Resources Conference, Bay St. Louis, MS, November 3-5, 2010.
4. Wax, C., 2010, A climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta shallow alluvial aquifer, status report presented to the Mississippi Water Resources Research Institute Advisory Board, Mississippi State, MS, November 9, 2010.
5. Wax, C.L., J. Pote, and R. Thornton, 2011, A climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta shallow alluvial aquifer, 2010 Mississippi Water Resources Conference Proceedings, p. 124, http://www.wrri.msstate.edu/pdf/2010_wrri_proceedings.pdf.
6. Wax, C.L., J. Pote, 2011, A climate-driven model to serve as a predictive tool for management of groundwater use from the Mississippi Delta shallow alluvial aquifer, final technical report submitted to Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 13 pgs.

Mississippi Water Resources Research Institute (MWRRI)

Final Technical Report – (From) 03/01/10 – (To) 02/28/11

Project Title: A climate-driven model to serve as a predictive tool for management of l groundwater use from the Mississippi Delta shallow alluvial aquifer (fund #331277/831277)

Principal Investigator: Charles L. Wax, PI (co-PI Jonathan Pote)

Institution: Department of geosciences, Mississippi State University
Address: P.O. Box 5448, Mississippi State, MS 39762
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Approximate expenditures during reporting period:

Federal: $13,779 Non-Federal: $60,000 (in-kind) Cost Share: $32,837

Equipment purchased during reporting period: none

Abstract:

The objective of this research was to develop a model that can be used as a management tool to find ways to meet the needs for water use while conserving groundwater. This is the third phase of the project to meet these objectives. In phase one of the project, the growing season precipitation was used to develop a relationship that estimated irrigation use, and this was the driving mechanism of the model that simulated water use to the year 2056. Phase two added the use of surface water when growing season precipitation was 30% or more above normal. In this third phase, a new climatological input was introduced into the model—irrigation demand. Irrigation demand was calculated using daily precipitation, evaporation, and a crop coefficient to estimate daily water needs by crop type. Daily values were summed to one week segments which were added to derive the total growing season irrigation demand. Weekly summations increased temporal resolution, improving model efficiency in accounting for excess daily rainfall, allowing the model to apply excess rainfall in subsequent days.

Research completed:

Figure 1 shows the inputs to the model and the resulting estimate of annual water uses for Sunflower County. This effective rainfall compared to irrigation use provides a much-improved rainfall-irrigation coefficient for use in the model
The model is constructed in an Excel spreadsheet. The interactive model file is sent as a separate file along with this report.

	A	B	C	D	E	F	G	H
1	2008/2055							
2	Total Acres							
3	COTTON	% furrow	% pivot				GS Precip	Seasonal ID
4	60300	0.81	0.19				18.69	0.46804775
5	RICE	% contour	% straight	% MI	% ZG			
6	27600	0.2	0.56	0.12	0.12		18.69	2.9971192
7	CORN	% furrow	% pivot	% Str	% ZG			
8	8910	1	0	0	0		18.69	1.16513959
9	SOYBEANS	%furrow	% straight	% pivot	% contour	% ZG		
10	86350	0.49	0.4	0.03	0.06	0.02	18.69	0.92303002
11	CATFISH	% MF	% 6/3					
12	24300	0.34	0.66					

I	J	K	L	M	N	O
Furrow Use	Pivot Use				Water Used	
0.491450139	0.369757724				**28240.21337**	
Con Use	St Use	MI Use	ZG Use			
3.62651423	3.17694635	2.667436086	1.678386751		**83514.60657**	
Furrow Use	Pivot Use	Str Use	ZG Use			
1.24669936	0.582569794	1.38651611	0.827249108		**11108.0913**	
Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
1.043023924	0.803036119	0.904569421	0.83995732	0.526127112	**79472.50179**	
MF Use	6/3 Use					
3.3525	0.785833333				**40301.55**	**242637**

Figure 1. Model illustration

Methods

In order to assess the change in volume of water in the aquifer, it was necessary to collect climatological data, crop coefficient formulas, crop data, and water use data for the growing season. Growing season was defined as May through August. In this study, all but the evaporation data were collected and analyzed for Sunflower County only. It was assumed that climate and cultural land uses (crops, acreages, irrigation methods) in Sunflower County were representative of the entire Delta region. These data were used in a model that was developed to identify and account for relationships between climatological variability and cultural water use. The model is interactive, allowing the user to change input values and alter the final output, thus allowing for specific scenarios to be simulated. Successive alternative combinations of variables were simulated with the model to determine possible methods and strategies to aid in groundwater conservation and management.

Climatological Data-

The precipitation record from Moorhead, MS (located centrally in Sunflower County) and the evaporation record from Stoneville, MS were used in the analysis. The data were arrayed in an Excel spreadsheet, and missing data were identified. Gaps in the data were filled with data from the next-nearest climate station location. The result was a serially complete and homogeneous daily record of precipitation and evaporation from 1961-2009. The evaporation data were used to represent potential evaporation (PE), or the demand of the atmosphere for water. To include consideration for the physiological demand of different crops at different phenological stages, the PE was modified by crop coefficients.

Crop coefficient formulas-

The SCS (1970) established consumptive crop use coefficient curves for a variety of crops. Ranjha and Ferguson (1982) matched these values with curves of best fit and derived the following equations to calculate a crop coefficient for three crops, using crop age in days from emergence as input:

$$\text{CC (Soybeans)} = 0.21-(2.97)(\text{DAY})10^{-3}+(4.74)(\text{DAY})^{2}10^{-4}-(4.03)(\text{DAY})^{3}10^{-6}$$

$$\text{CC (Corn)} = 0.12+(0.01)(\text{DAY})+(0.18)(\text{DAY})^{2}10^{-3}-(2.05)(\text{DAY})^{3}10^{-6}$$

$$\text{CC (Cotton)} = 0.11-(0.011)(\text{DAY})+(0.55)(\text{DAY})^{2}10^{-3}-(3.49)(\text{DAY})^{3}10^{-6}$$

Crop Data

Crop data for cotton, rice, soybeans, corn, and catfish were collected from the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS). For the five crops, total acres and total irrigated acres were retrieved for the years 2002-2009 (the only years for which measured water use data were available).

Water Use Data

Water use data were supplied by Yazoo-Mississippi Delta Joint Water Management District (YMD) in acre-feet/acre (A-F/A). For 2005 through 2009, these data were divided into the amount of water used by each specific irrigation method for cotton, corn, soybeans, and rice (as determined by a survey of about 140 sites monitored by YMD shown in Figure 4), as well as the total average water use for each of the crops. For 2002-2004, only the total average water use amount for each of the four crops was provided. Therefore, a ratio based on the 2005-2008 specific irrigation methods-to-total average water use from 2002-2004 was formulated to identify relationships between the given average water use and constituent water use amounts associated with each specific irrigation method for each crop for the years 2002-2004 (Merrell, 2008).

Catfish water use is dependent upon whether the producer uses the maintain-full (MF) or the drop-add (6/3) management scheme. Only total average water use by catfish ponds was provided by YMD, also in A-F/A, and only for 2004 and 2006. So, the catfish water use model developed by Pote and Wax (1993) was used with the Moorhead climate data to estimate the amounts of water used by each of the management schemes in Sunflower County for the period 1961-2009. A ratio between the total average water use and the water use associated with the two possible management schemes in catfish ponds was developed, similar to the water use amounts determined for the specific irrigation methods of the row crops and rice. As shown in Table 3, an average of the four years for which measurements were available was calculated to obtain the percentage of water use by each of the management schemes.

These water use data for row crops, rice, and aquaculture were combined with acreage data to calculate the total amount of water used for irrigation for each crop in the county in 2006. This analysis provided an evaluation of water use by crop type which was the basis for developing a static model. The static model was used as a standard against which all other scenarios of climatic variability, land use and management changes were compared.

Irrigation demand-water use relationship

Recognizing that the amount of rainfall during a growing season significantly influences the amount of irrigation needed, a method was developed to account for this climatological variability. Total growing season precipitation was initially used, but problems with timing and distribution of rainfall through the growing season led to a weak relationship in some years. It was therefore decided to increase the resolution of the model and therefore refine effective precipitation estimates by examining moisture deficits and surpluses on a daily basis.

In addition to atmospheric demand (evaporation), crop water demand was introduced into the model by use of a crop coefficient relating crop water use to phenological stage. Evaporation data and the crop coefficient combine the climatic demand and crop demand to estimate the total daily demand for water. Irrigation demand is derived for each day by subtracting the calculated daily total demand for water from daily precipitation.

Daily accounting of water demand resulted in the use of only rainfall needed to satisfy each day's specific irrigation demand, discarding the excess rainfall for that day. In reality, the environment does not "restart" each day; that extra moisture would be saved in the soil and applied to the next few days' water need, reducing the irrigation demand over those few days. In order to more accurately model actual field practices, daily irrigation demand values were summed by weeks through the growing season, capturing the "excess" rainfall on any day and thereby reducing the weekly demand for irrigation. The weekly values were then summed to get a total seasonal irrigation demand. This more realistically calculated irrigation demand was regressed against actual seasonal water use, as measured by YMD, to find the relationship to predict actual water that will be used in any year. Calculated seasonal irrigation demand is now used as the climatological variability input to drive the model.

Table 1 shows how growing season calculated irrigation demand was regressed against measured total average water use for cotton, corn, soybeans, and rice for 2002-2009 to develop the function for estimating the amount of water use by crops based on the amount of irrigation demand. Figure 2 shows a comparison of measured water compared to the water use calculated by this method for the row crops and rice for the period 2002-2009. Figure 3 shows an example of calculated irrigation demand for Corn from1961-2009, and compares the calculated demand against the measured irrigation from 2002-2009. Catfish water use was obtained from model-estimates based on daily rainfall rather than total growing season rainfall. In this manner, water use by all five crops was linked to climatic variability each year.

Table 1. Predictive equations developed from regressing calculated irrigation demand against measured water use

	Cotton			Corn	
	Calculated	Measured		Calculated	Measured
2002	0.45	0.5		0.90	0.9
2003	0.41	0.5		0.61	0.6
2004	0.42	0.3		0.57	0.4
2005	0.51	0.5		0.79	1
2006	0.60	0.8		1.20	1.2
2007	0.61	0.5		0.67	0.8
2008	0.47	0.6		1.17	1.2
2009	0.52	0.3		0.99	0.8
	Y=0.494867(X)+0.232725			Y=1.180774(X)+0.001839	
	Soybeans			Rice	
	Calculated	Measured		Calculated	Measured
2002	0.65	0.68		3.02	3.2
2003	0.48	0.64		2.62	2.8
2004	0.45	0.37		2.69	2.5
2005	0.71	0.6		3.05	3
2006	0.93	1		3.34	3.4
2007	0.75	0.8		3.09	3
2008	0.93	1		3.00	3.1
2009	0.79	0.6		3.01	2.8
	Y=1.105858(X)+0.026753			Y=1.111286(X)+1.671355	

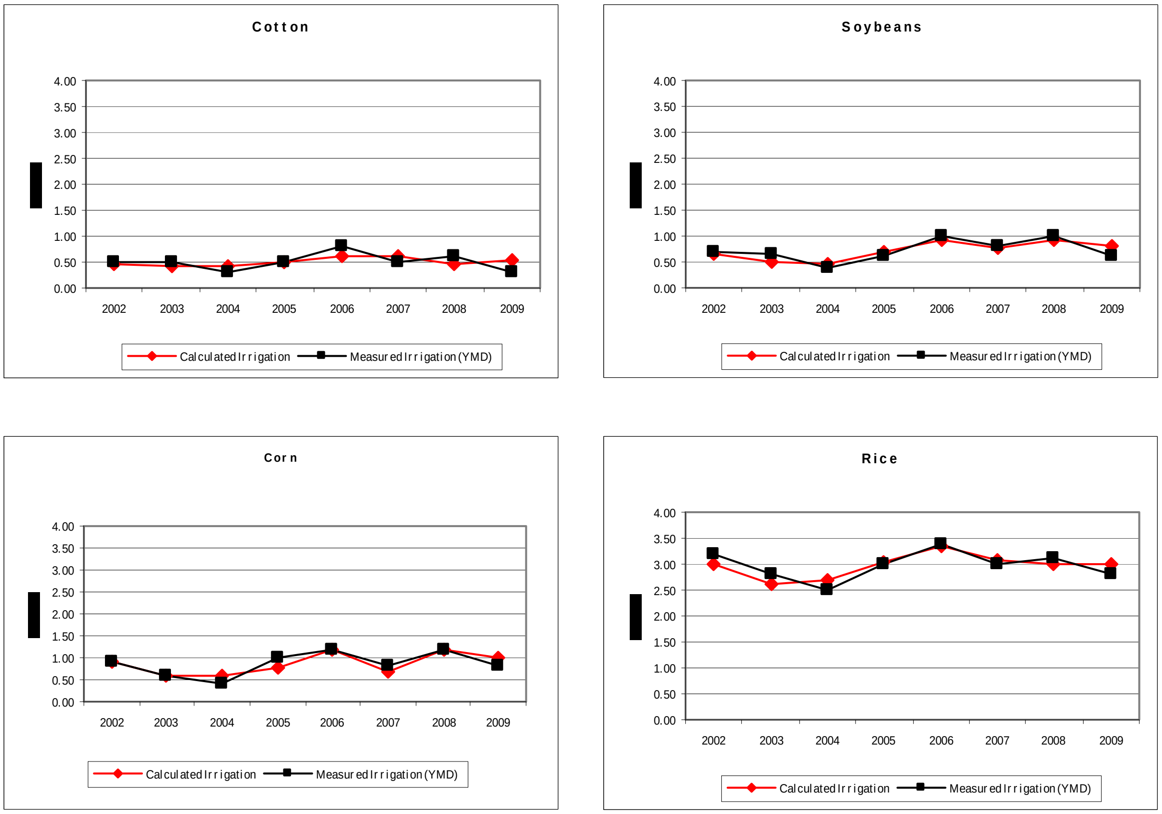

Figure 2. Comparison of calculated and measured water use.

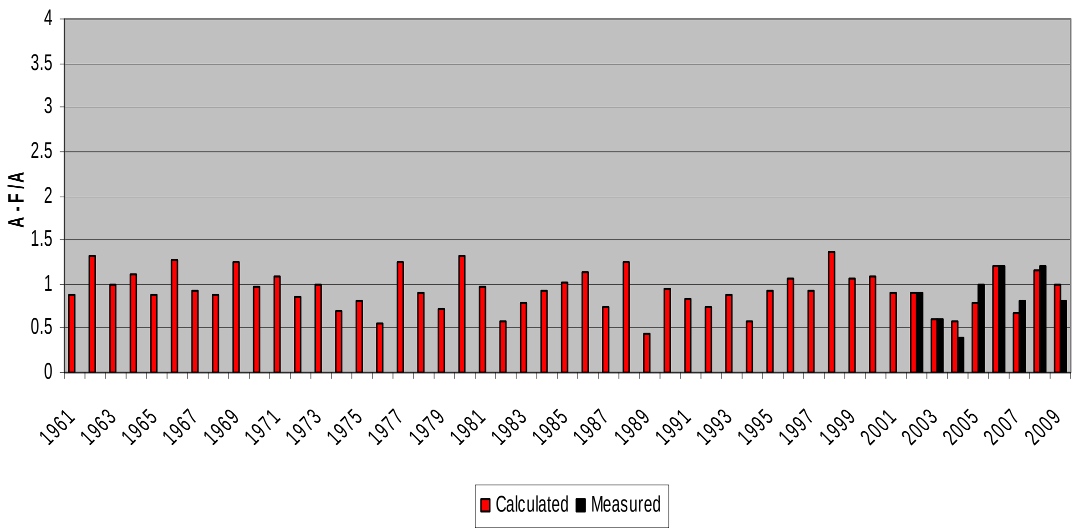

Figure 3: Calculated (1961-2009) vs. Measured (2002-2009) Corn Irrigation

($Y=1.180774(x) + 0.001839$; $R^2=0.77$)

Model Results

The climate data, crop data, water use data, and irrigation demand - water use relationships were used to develop a model that could assess water volume declines in the aquifer over a growing season. The model calculated amounts of water taken from the aquifer by each specific irrigation method and management method for each of the five crops. The model then summed the specific water uses for each year, resulting in a total annual reduction in the volume of water in the aquifer.

Using the Sunflower County 2006 land use and crop water use relationships with irrigation demand-water use relationships developed for each crop, calculated irrigation demand from the past 48 years (1961-2009) was used as a variable in the model to estimate the total water use for each year 48 years into the future (2008-2056). The average of the annual recharge volumes measured in the aquifer between 1989-2009 was then used with the modeled water volume declines each year to characterize the cumulative water volume changes over the 48-year period. The model was subsequently used to simulate different scenarios of water use by changing crop acreages or irrigation methods from the static 2006 data.

Four scenarios were simulated with the model. The simulations and results are as follows:

<u>The static 2006 scenario</u>

The Static 2006 scenario reflected what the state of aquifer would be if no changes were made in the climate or cultural land uses or practices throughout the period. All crop acreages, irrigation methods, and percentages of irrigation methods remained the same as documented in 2006. As shown in Figure 4, during the first ten years, water volumes in the aquifer slowly declined. This occurred because growing season precipitation was below normal during these years causing the demand for irrigation to rise; therefore, in those years, withdrawals exceeded recharge. For the next approximately 30 years, the volume of the aquifer reached a stationary level. This can be attributed to two factors. First, there are a number of years during this period that growing season precipitation far exceeds the average, allowing for greater recharge to occur. Secondly, managers at YMD began to make conservation efforts, and believe that the results of those efforts are evident in the rebounding water levels. In the last seven years, there is again a marked decline. This could be attributed to the fact that there were a number of drought years during the period, and the amount of precipitation received was not sufficient to sustain levels due to withdrawals for irrigation.

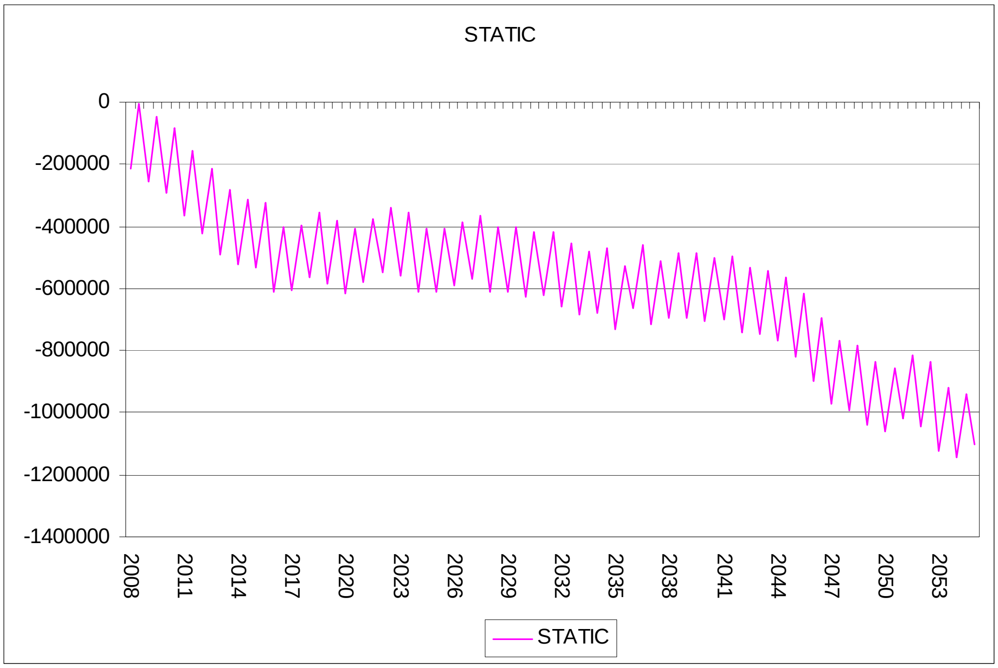

Figure 4. Static 2006 model simulation

Most Conservative Irrigation Methods Implemented Scenario

The most conservative irrigation method for each crop was used to determine the effects water conservation efforts could have on the aquifer for the 48 year period. In this scenario, the most conservative method for each crop was the only method used for irrigation. For example, 100% of cotton irrigation was assigned to center-pivot irrigation, and all other methods of irrigation of cotton were assigned a value of 0. All other irrigation methods for the conservative and consumptive scenarios are shown in Table 2. Figure 5 shows the difference between the static 2006 "base" model (blue) and the state of the aquifer after the conservation changes were made (red). The result is an increase of approximately 3,000,000 acre-feet of water in the aquifer over the entire period, with a consistent increase in water volume throughout time as recharge overcame withdrawal year after year.

Table 2. Irrigation methods used in conservative and consumptive scenarios

	Irrigation Method	
Crop	**Conservative**	**Consumptive**
Cotton	pivot	furrow
Rice	zero-grade	contour
Corn	pivot	straight
Soybeans	zero-grade	pivot
Catfish	6/3	MF

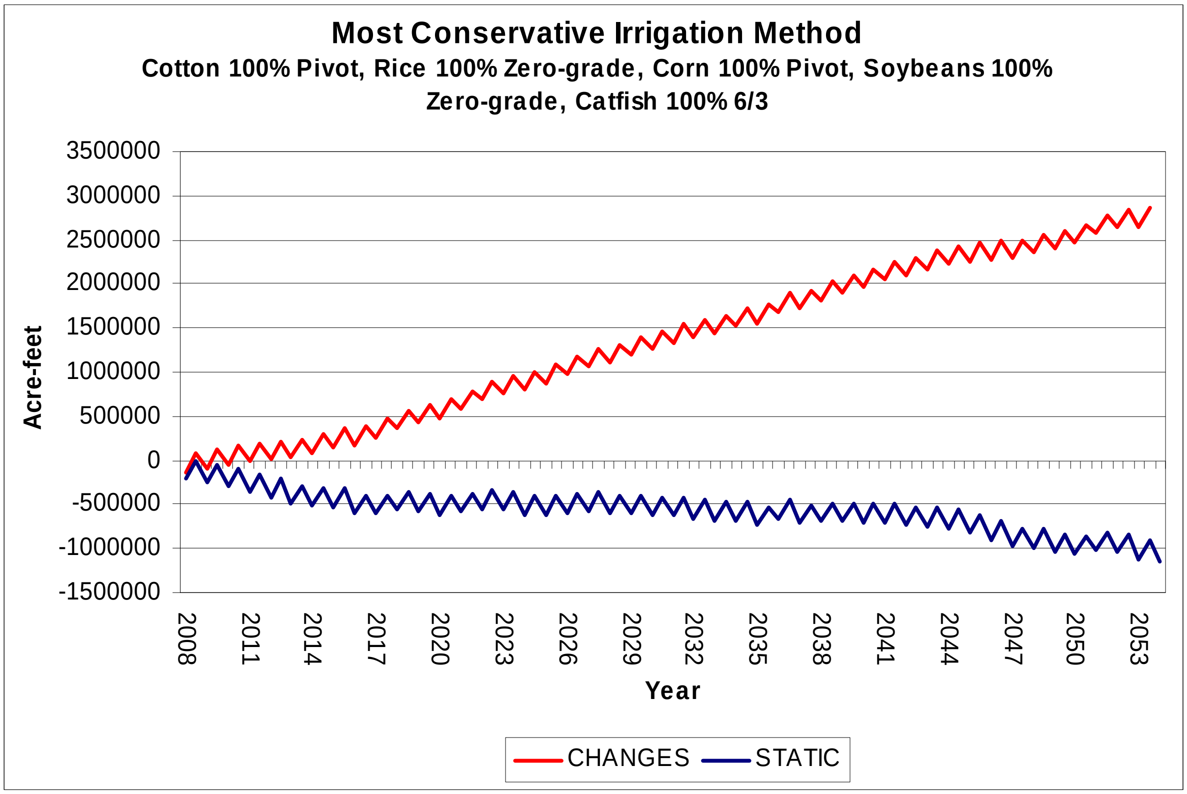

Figure 5. Most conservative irrigation method implemented

<u>Most Consumptive Irrigation Methods Implemented Scenario</u>

This scenario is the opposite of the previous scenario and represents a situation in which the most consumptive irrigation method is implemented. This particular scenario and its resulting output would be a good example to use when conveying to farmers, producers, other water consumers, and planners the need for conservation practices. As shown in Figure 6, if the most consumptive irrigation method was used for each crop, the aquifer would lose approximately 30,000,000 acre-feet of water over the 48-year period by experiencing a consistent annual loss of water volume as more water was withdrawn than recharge could replace. It is not known at what point the aquifer would be completely de-watered.

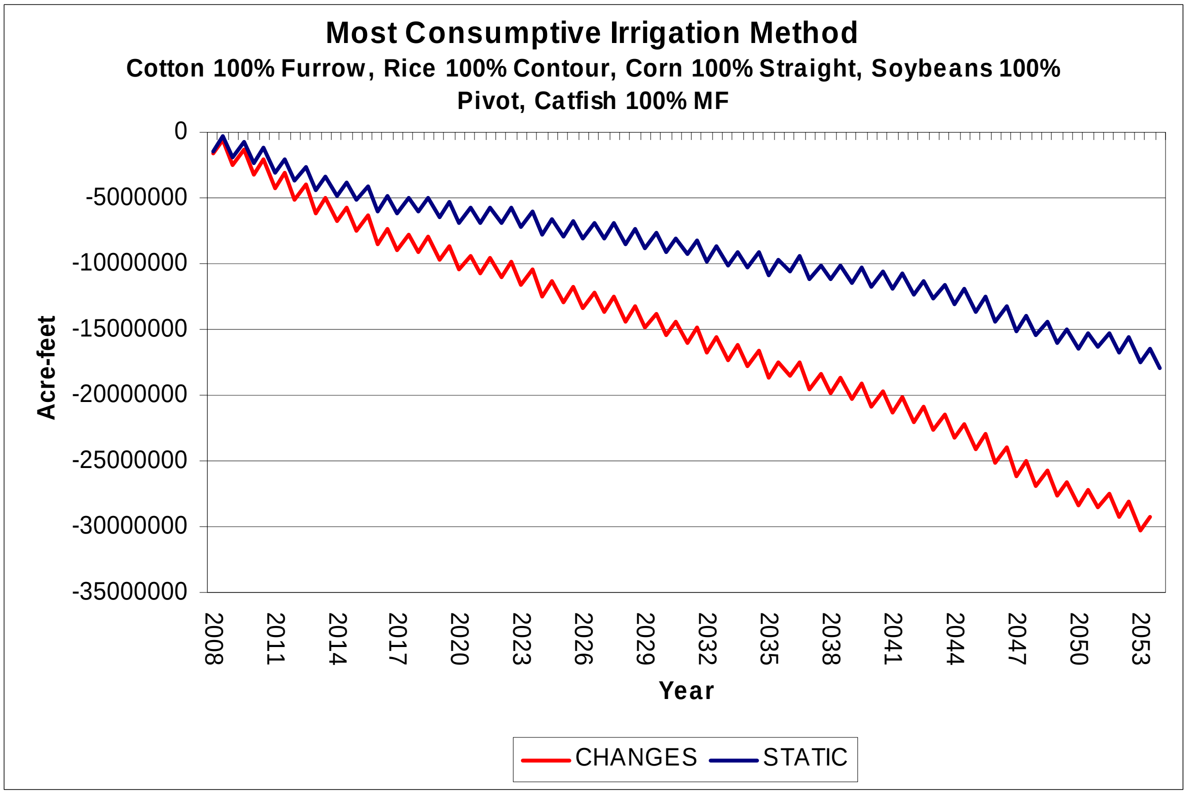

Figure 6. Most consumptive irrigation methods implemented

Use of surface water scenario

Figure 7 shows results of using surface water in lieu of groundwater in combination with the use of the new irrigation demand as the climatological driver for the model for the 48-year period 2008-2056 (and incorporating the wet year 2009). Using surface water for 25% of irrigation demand when growing season rainfall was 30% or more above average resulted in consistent declines in water volume from the beginning of the period until about 2017. During this 10-year period there were no years in which growing season precipitation met the 30% above normal threshold. From about 2017 to 2044 water volumes in the aquifer increased or stayed level, well above what the volume would have been each year if no surface water had been used. Beginning in 2044 another group of years occurred when the precipitation did not meet the 30% threshold and water volumes declined accordingly until the end of the period, but still ended about positive 1,000,000 A-F above the static scenario.

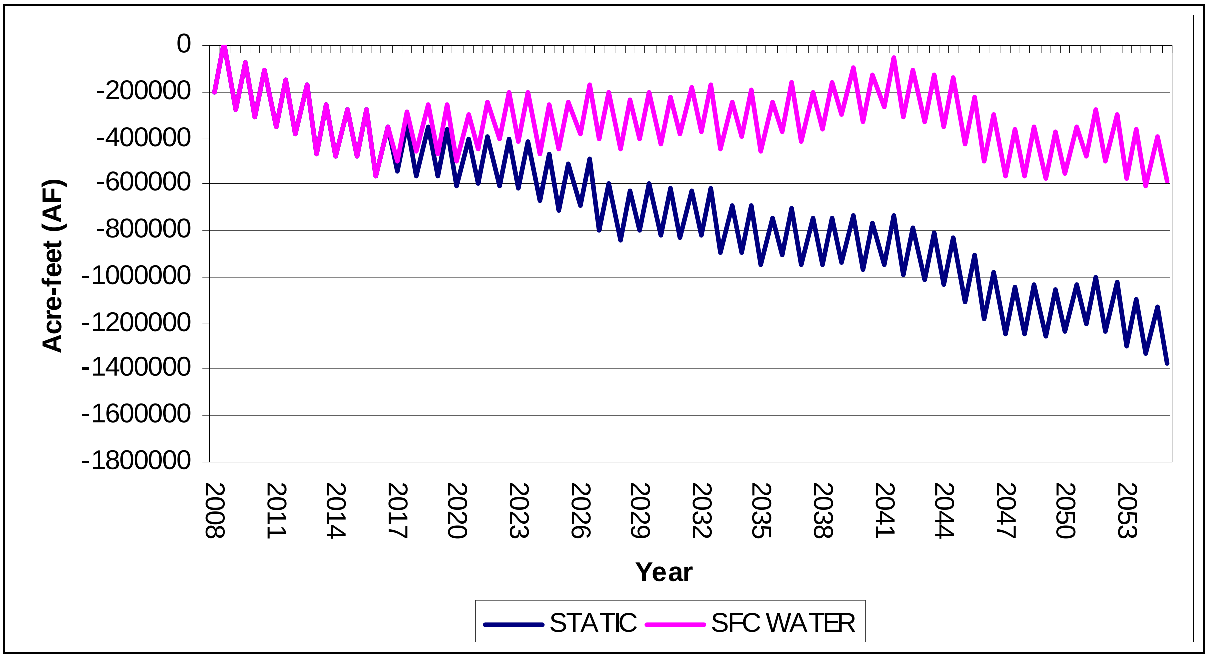

Figure 7. Model results 2008-2056 when surface water irrigation is implemented and irrigation demand is used as the climatological driver

Significant Findings

1. The amount of water withdrawn from the aquifer each year for irrigation is directly related to climate inputs--specifically precipitation, evaporation, and resulting plant water demand.

2. The aquifer volume responds positively and quickly to changes in management strategies and land use changes.

3. Use of surface water in lieu of groundwater for irrigation in years when growing season precipitation is 30% or more above average can significantly reduce aquifer drawdown in that year, resulting in a faster recovery of volume in the aquifer during the recharge period. Figure 8 shows how often precipitation could supply crop water needs for each of the row crops and rice through the 49-year period by comparing calculated irrigation demand and total growing season precipitation. The bars above the mid-line represent years when the climate delivers “extra” water, more than the crops can use. These are years when the extra, or surplus, water could be stored. The bars below the mid-line represent years when rainfall is not sufficient to meet the needs of the crops. In these years, 100% of the water delivered by the climate is used and the crop needs must be supplemented with additional groundwater irrigation.

The analysis concludes that climate could provide the entire water need of the plants in 70% of the years for corn, 65% of the years for soybeans and cotton, and even 5% of the years for rice. Even though the distribution of the extra water through the growing season may rule out total dependence of producers on this source of water, this analysis does demonstrate that extra water delivered by the climate could be a source of water that could be used often in place of pumped groundwater. Instituting this practice could save energy, save producers money, and enhance the sustainability of the aquifer.

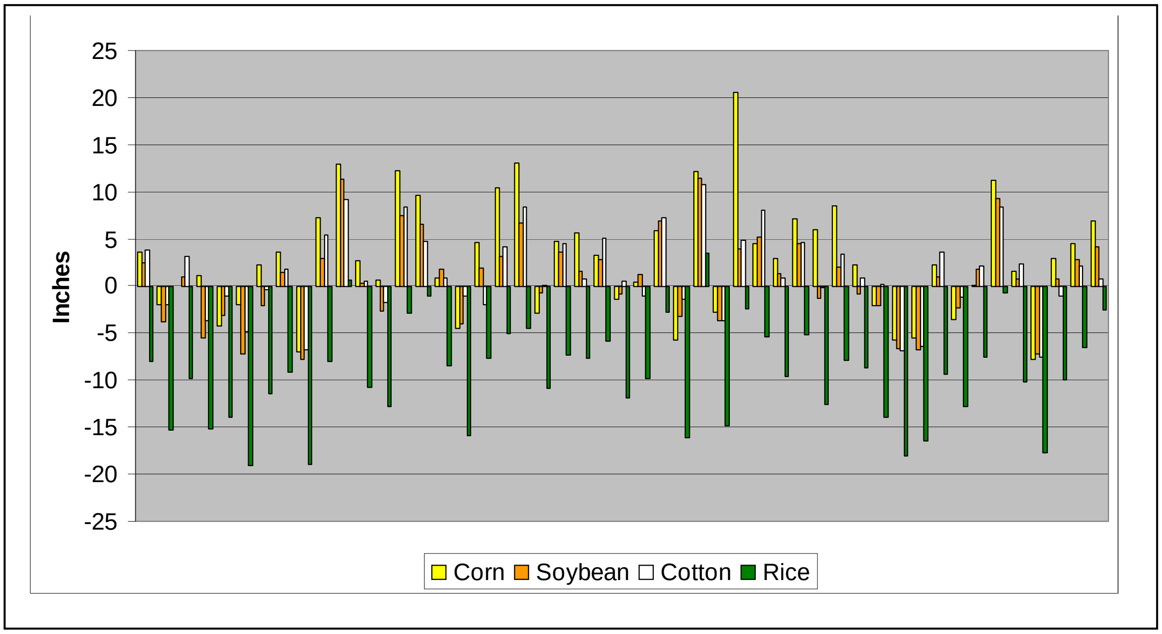

Figure 8. Effective precipitation—years in which climate delivers a surplus or a deficit of precipitation to meet crop water needs.

References

Merrell, Tia L., 2008. “Development of an Interactive Model Predicting Climatological and Cultural Influences on Annual Groundwater Volume in the Mississippi Delta Shallow Alluvial Aquifer.” MS Thesis, Mississippi State University.

Pote, J.W. and C.L. Wax, 1993. "Modeling the Climatological Potential for Water Conservation in Aquaculture." Transactions of the American Society of Agricultural Engineers, Volume 36 (5), 1343-1348.

Ramkja, A.V. and K.A. Ferguson. 1982. On-farm irrigation scheduling by computer simulation in Arkansas. Presentation, ASAE Southwest Region Meeting, April, 1982, Shreveport, LA.

Soil Conservation Service, 1970. Irrigation water requirements, Technical Release No. 21, U.S. Department of Agriculture, Washington, DC.

Problems Encountered:

Identifying controls of aquifer recharge rates has not been successful. Attempts to relate recharge to Mississippi River stage on the west, to Grenada Lake stage on the east, and to non-growing season precipitation totals on both east and west sides of the delta have not been successful. Annual recharge used in the model scenarios was the average of the 19 years of measured recharge supplied by YMD. Changes in cultural practices adopted for the various model run scenarios are not known to be practical or economically feasible—these need to be confirmed as valid possibilities before rigid recommendations are developed. An attempt to make the model represent total water use across the entire delta region (not just Sunflower County) was not completed because irrigated acreages were not available for all the counties. Using the percentages of irrigated to non-irrigated acres measured for Sunflower County was not considered accurate after several unsuccessful attempts to estimate total delta-wide water use.

Publications/Presentations

1. Presentation of preliminary results to Mississippi Water Resources Research Institute External Advisory Board, November 2010.

2. Presentation of preliminary results to U.S. Army Corps of Engineers Climate Symposium, Vicksburg, MS, September 2010.

3. "Refining effective precipitation estimates for a model simulating conservation of groundwater in the Mississippi Delta Shallow Alluvial Aquifer". Presentation at Mississippi Water Resources Conference, Bay St. Louis, MS, November 2010. (Power Point slides sent as separate file along with this report)

Student Training:

Name	Level	Thesis	Major	Graduation
Robert Thornton	Ph.D.	Yes	Earth and Atmospheric Science	May 2012
Jason Sydjeko	M.S.	No	Geosciences	May 2011
Chas Swindoll	B.S.	No	Geosciences	May 2011

Report submitted by:
Charles L. Wax — February 23, 2011

Information Transfer Program Introduction

The Mississippi Water Resources Research Institute addresses research and outreach efforts targeted at maintaining plentiful, quality water supplies throughout the state. The Institute is a hub for information and expertise on water resources issues within the state and region. We do this in full partnership with our public and private cooperators.

The Mississippi Water Resources Research Institute is committed to providing public outreach, education opportunities, and assisting with economic development activities. Researchers and students have the opportunity to present their research by giving oral and poster presentations. Also included are plenary sessions and workshops. Those persons subscribed to the MWRRI listserv receive newsletters, award opportunity notices, job opportunities, conference information, and timely water-related information.

Information Transfer Program-Publications

Basic Information

Title:	Information Transfer Program-Publications
Project Number:	2010MS155B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3rd
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	, George M. Hopper

Publication

1. Mississippi Water Resources Research Institute, 2010, 2010 Annual Report, Mississippi State University, Mississippi State, MS, 32 pgs.

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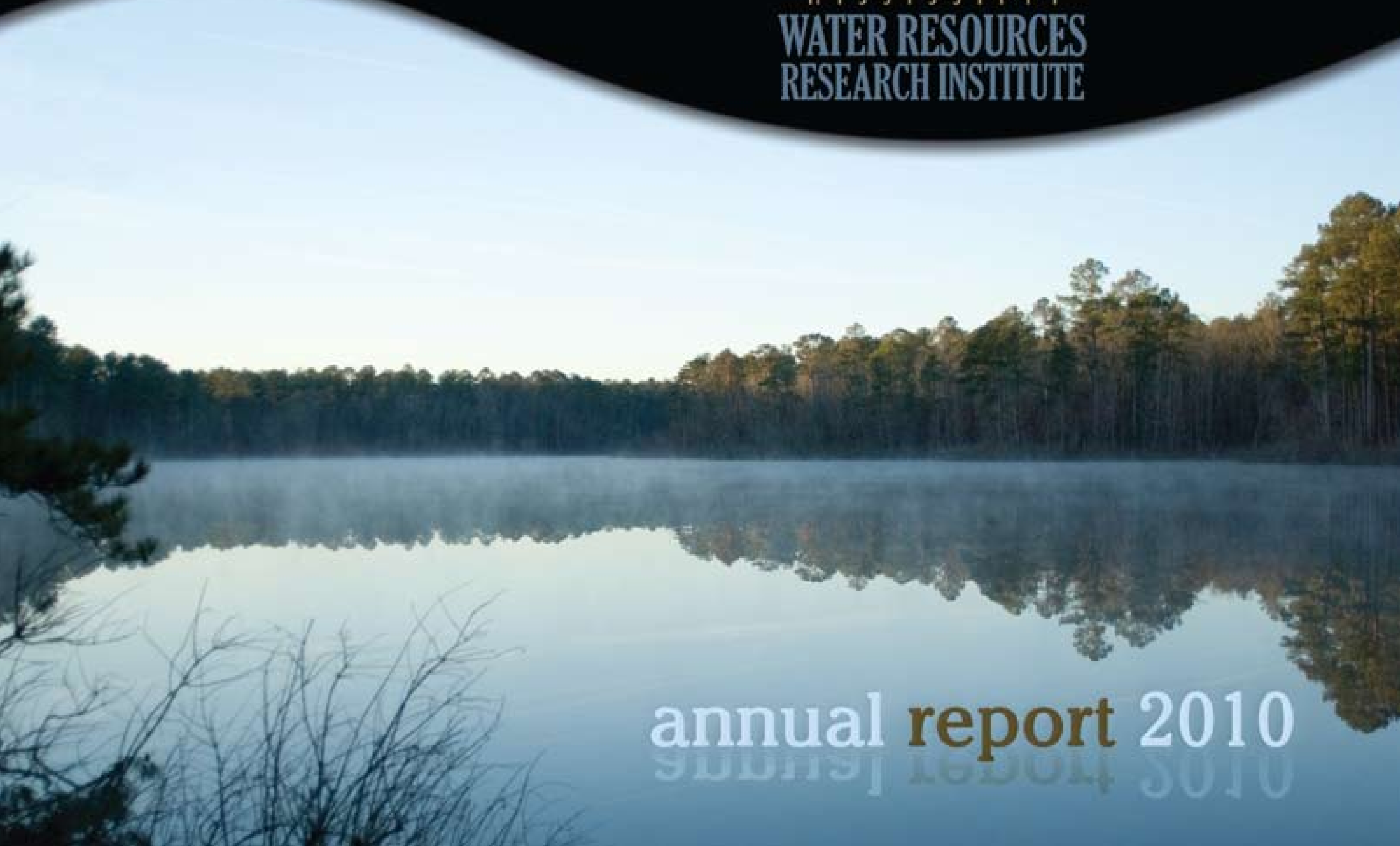


annual report 2010

MISSISSIPPI

WATER RESOURCES RESEARCH INSTITUTE

2010 ANNUAL REPORT

Director's Notes

Mississippi is fortunate to have plentiful supplies of clean water. Eighty percent of our state's water supply and 93 percent of our drinking water is obtained from ground water sources. The state has 18 major aquifer systems and numerous minor aquifers which supplies ground water throughout the state. However, we can not take these abundant water sources for granted, nor can we ignore the potential for contamination. As other southern states dispute over water rights, Mississippi must be proactive in protecting and sustaining our livelihood which is found in our natural resources, including abundant water supplies.

The Mississippi Water Resources Research Institute at Mississippi State University was established to address water issues facing our state. Working with our many partners throughout the state, the Institute is committed to providing public outreach, educational opportunities, and assisting with economic development activities. We are also committed to ensuring plentiful water resources for the next generation of Mississippians.

This report details many of the activities the institute is addressing on the most pressing water-related problems. Thank you for participating in these endeavors.

George M. Hopper

Mississippi Water Resources Research Institute

The Mississippi Water Resources Research Institute (MWRRI) provides a statewide center of expertise in water and associated land use and serves as a repository of knowledge for use in education, research, planning, and community service.

The MWRRI goals are to serve public and private interests in the conservation, development, and use of water resources; to provide training opportunities in higher education whereby skilled professionals become available to serve government and private sectors alike; to assist planning and regulatory bodies at the local, state, regional, and federal levels; to communicate research findings to potential users in a form that encourages quick comprehension and direct application to water-related problems; to assist state agencies in the development and maintenance of a state water management plan; and to facilitate and stimulate planning and management that:

- deals with water policy issues,
- supports state water agencies' missions with research on problems encountered and expected,
- provides water planning and management organizations with tools to increase efficiency and effectiveness.

The Mississippi Water Resources Research Institute is a unit of the Forest and Wildlife Research Center, Mississippi State University.

2009 Water Resources Conference

The 39th Annual Mississippi Water Resources Research Conference was held August 5-7 at Harrah's Resort and Casino in Tunica. More than 200 individuals attended the two and one-half day conference, which included 23 student presenters. The conference included 11 keynote speakers and offered 11 technical tracts including Delta Water Quality, Delta (Ag) Water, Wetlands, Delta Water, Sediments, Water Quality, Non-Point, Management/Sustainability, Wood Treatment, Modeling, and Soil and Water Treatment.

A student competition was held for both oral and poster presentations. Twelve student posters were presented with James Palmer, a Mississippi State University graduate student, garnering the top prize. His poster was on the possible correlations among simple visual disturbance estimates and hydrologic and edaphic parameters in forested headwaters of Mississippi. Sixteen students made oral presentations during the conference. Richard Lusk, Mississippi State University graduate student, received third place for his presentation on electrokinetic treatment of mercury contaminated soil at the mercury refining company superfund site. The second place winner, Olivier Bordonne is a graduate student from Strassbourg, France. Bordonne is currently interning with U.S. Geological Survey. His research was on the interaction of the Mississippi River and its Alluvial Aquifer in Northwestern Mississippi. The first place winner was Lauren Mangum, a Mississippi State University graduate student, whose presentation was on treatment of Timtek process water by co-composting.

The conference was sponsored by the state's Department of Environmental Quality, Water Resources Association, and Water Resources Research Institute, along with the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey. Student prizes were funded by Clearwater Consultants, Pickering Inc., and Mississippi Water Resources Association.

USGS-funded Projects

Over the past eight years (2003-2010) topics for research funded by the U.S.G.S. have included water quality, biological sciences, groundwater flow and transport, and climate and hydrologic processes with focus areas in non-point pollution, sediments, invasive species, management and planning, nutrients, pesticides, toxic substances, surface water, water use, and climatological processes. This research has generated **30 presentations** at the Annual Mississippi Water Resources Conference, **29 written papers** and final reports, and **17 peer-reviewed journal articles**. Five master's students wrote theses on their USGS research. Training has included one high school student, **33 undergraduate students**, **38 master's students**, and **15 Ph.D. candidates**. There were **19 assistant professors**, **13 associate professors**, and **6 professors** performing research at **four Mississippi universities**.

MWRRI-funded Projects

These projects reflect the success of the institute to facilitate strong relationships between university researchers and Mississippi's state agencies and other organizations to identify and address priority water resource issues. These projects all include partial cost share from a participating non-federal agency or organization.

Natural Enhanced Transport of Agricultural Lead and Arsenic through Riparian Wetlands

Gregg Davidson, Geology and Geological Engineering, University of Mississippi

Riparian wetlands are perceived to be efficient scavengers of a wide variety of non-point source pollutants. Confidence in the ability of riparian zones to buffer anthropogenic inputs has been derived primarily from studies of active inflow and outflow of chemical-laden water and sediment entering and exiting riparian systems. Research results have revealed that short-term studies documenting sequestration of chemically persistent contaminants in riparian wetlands are not sufficient to document the long-term containment of these two substances. Earlier research indicated that elevated concentrations of Pb and As were found at particular depths in open-water sediments in Sky Lake but not in the same sediments deposited in the surrounding wetlands. Depositional dates of the elevated concentration-based ^{210}Pb and ^{137}Cs measurements were consistent with the timing of lead and arsenate used for boll weevil control in surrounding cotton crops . The absence of similar concentration spikes in the wetland sediments led to the hypothesis that contaminants such as Pb and As may be initially scavenged from water flowing through a riparian wetland, but over time, are flushed out into adjacent lakes or streams. Permanent sequestration occurs only with burial in the perennially flooded open water environment. To determine if evidence of long-term flushing of contaminants from riparian wetlands is a common occurrence, the research project expanded to additional lake-wetland systems in the Mississippi Delta region.

Monitoring and Modeling Water Pollution in Mississippi Lakes

Cristiane Q. Surbeck, Department of Civil Engineering, University of Mississippi

Sardis Lake, a U.S. Army Corps of Engineers flood-control reservoir, is an important financial and social resource. The 98,000 acre impoundment stretches through Panola, Lafayette, and Marshall counties in Northwest Mississippi. Activities associated with the reservoir contribute some $16.7 million to the economy through recreation-related sales. A project in the Institute is studying water quality at the 70-year-old reservoir.

High concentrations of fecal coliform bacteria and other fecal indicator bacteria have been found present in the waterbody. Water collection studies have indicated that *E. Coli* concentrations were above the maximum concentration allowed by USEPA. A likely cause of the high concentrations is the consistent presence of dozens of birds in the vicinity. Distinct decay rates for bacteria were also found specific to each microcosm.

Further research is needed, with a sufficient number of repetitions, to enable a comprehensive statistical analysis of results. Collections taken during different seasons would also assist in determining when bacteria concentrations are at their highest and what water quality indicators could be a primary influence on bacteria concentrations. Additional water sampling should coincide with a study of sediment particle size to determine its association with bacteria concentration.

Results will help determine mechanisms of die-off and survival of fecal indicator bacteria in water that is located in tributaries and in an embayment between Thompson Creek and Lower Sardis Lake.

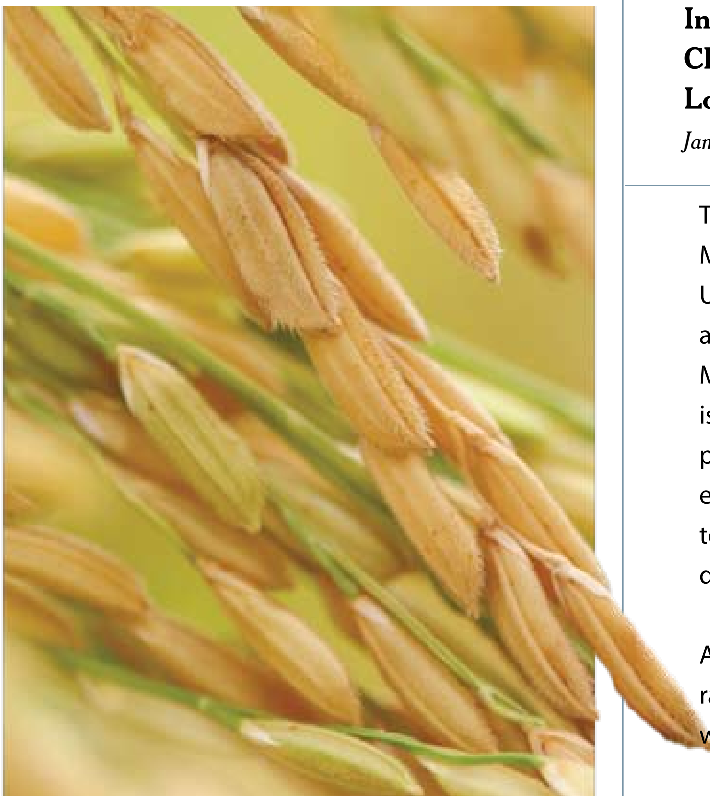
MWRRI-funded Projects

Watershed Assessment and Education

Maifan Silitonga, Mississippi River Research Center, Alcorn State University

The Coles Creek Watershed, located in the southwestern quadrant of the state of Mississippi, is in the EPA Section §303(d) list of impaired waters. Degradation of the ponds/lakes and streams/creeks in this watershed is caused mostly by biological impairment, followed by nutrients, organic enrichment or low dissolved oxygen, sediment/siltation, pesticides, and pathogens. These impairments cause the degradation of water quality thus causing euthrophication or algal bloom that can lead to fish kills and can also adversely affect human health.

Water and soil samples from these ponds have been collected and are being analyzed for nutrient contents, and physical and biological parameters. The analysis will allow scientists to determine the best alternative management practices to be adopted by community residents. Educational materials are being developed to engage the community in protecting the quality of water. This information is also being taught to landowners who own private ponds. Community participation is needed to improve, maintain, and restore the quality of water in this area.



Influences of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain

Jamie Dyer, Department of Geosciences, Mississippi State University

The Mississippi River floodplain in northwestern Mississippi is a key agricultural region in the southern United States. Almost 80 percent of Mississippi's agricultural products originate in this area, known as the Mississippi Delta. This is considerable since Mississippi is the third largest producer of cotton and fourth largest producer of rice in the United States. Delta agriculture enterprises comprise about 33 percent of Mississippi's total cash receipts. Both local and state economies are dependent on agricultural production in the Delta.

Agriculture is dependent on precipitation due to high rates of evapotranspiration during the growing season as well as the moisture required for local crops to succeed.

Precipitation, however, is a difficult climate variable to predict with respect to depth and coverage due to the factors involved during summer growing season when small-scale convective events provide a majority of the precipitation. Because of the climate variability, precipitation research is and has been of key importance to the maintenance and development of agriculture in the Mississippi Delta.

A strain on agriculture has been felt due to recent droughts in the southeast United States; especially in Mississippi. Understanding the patterns of precipitation could help identify the extent and frequency of these events for future water resource management. Research may reveal that variations in land use / land cover and the extent of agricultural irrigation may be influencing the spatial and temporal extent of precipitation. Therefore, it is crucial to define and understand meteorological mechanisms associated with rainfall generation and distribution over the Mississippi Delta and surrounding areas. This information will be useful to water resource managers as well as local and regional agricultural consultants and departments to identify surface and atmospheric mechanisms related to regional rainfall patterns.

Water Quality and Other Ecosystem Services Performed in Wetlands Managed for Waterfowl in Mississippi

Richard M. Kaminski and Amy S. Spencer, Department of Wildlife, Fisheries and Aquaculture, Mississippi State University

Wetlands are ecologically, environmentally, and economically valuable worldwide. Natural moist-soil emergent vegetated wetlands, abundant in the Lower Mississippi Alluvial Valley, are generally flooded during fall-winter and then dewatered naturally by evaporation or by managers during spring-summer to promote growth of annual grasses and sedges. The life-history strategies of these plants are adapted for production of abundant seeds or tubers that are used by a wide diversity of waterfowl and other wetland wildlife. Within agricultural landscapes, strategic location of moist-soil wetlands amid farmed lands can reduce dispersal of sediments and other nutrients into surrounding watersheds and thus enhance water and environmental qualities. Additionally, seasonal decay of native vegetation in wetlands sustains nutrient cycling and is the foundation of disintegrated-based food webs in these systems. Crayfish (*Procambarus* spp.) and other aquatic invertebrates inhabiting moist-soil wetlands are bio-indicators of quality freshwater wetlands. Crayfish can also provide additional economic gain and food for landowners.

This research will generate baseline water quality data for describing potential watershed improvements provided by moist-soil management. Factors which contribute to the formation of a disintegrated-based food web of crayfish and other invertebrates within these managed wetlands will also be modeled. Finally, scientists plan to estimate the population size, survival and recruitment of crayfish populations to assess economic potential for sustainable harvest of this resource from natural wetlands for human consumption. The research is targeted at increasing awareness of moist-soil management for improved water quality, wetland conservation, biodiversity, and potential economic returns for pubic and private lands in Mississippi.

Assessing the Effectiveness of Measures to Reduce Sediment Loads in Surface Waters Using ^{210}Pb Activity in Lacustrine Sediments

Gregg Davidson, Geology and Geological Engineering, University of Mississippi

Efforts to improve surface water quality have focused on reducing contaminants, excess nutrients, and suspended sediment. The sediment in waterways is a result of erosion of adjacent lands; therefore, successful reduction of sediment loading ultimately means successful erosion control. Assessing erosion by measuring sediment loads in streams is complicated by large spatial and temporal variability and presents difficulties in measuring sediments transported in channels.

A solution to remediating these difficulties is to quantify the rate of sediment accumulation in the lakes or wetlands that receive sediment laden runoff water. Since lakes and wetlands serve as natural sinks for eroded sediment, they preserve a record of both ancient and modern rates. Radio-lead or ^{210}Pb is ideally suited with a half life of 22 years. A series of ^{210}Pb measurements taken at different depths yields a log-activity verses depth relationship from which a rate of sediment accumulation can be calculated.

Mississippi watershed locations suitable for this study include Bee, Washington, Wolf, Moon, and Beasley. The results of initial core sampling will be used to target specific depths for collection of the second core. Core analysis which indicates recent sediment accumulation rates have dropped below 0.5 cm per year will be sampled again for analysis in increments finer than 1 cm. This research will assess the effectiveness of erosion control measures by targeting the historical sediment record stored in lakes and wetlands downstream of the erosion control measures.

MWRRI-funded Projects

Water-Conserving Irrigation Systems for Furrow and Flood Irrigated Crops in the Mississippi Delta

Joseph Massey, Plant & Soil Sciences, Mississippi State University

Significant declines in the Mississippi River Valley Alluvial Aquifer have occurred over the past 20 years. As a result of this decline, improved crop irrigation practices have become extremely important. The goal of this project is to improve water use efficiency for one of the most economically important cropping rotations which is practiced in the Mississippi Delta—soybean-rice rotation. Past planting history has typically been two years of soybean followed by one year of rice. Rice and soybean represent an economic value of $432 million for soybean and $214 million for rice.

The objectives of this research are to use a systems approach to calculate water-saving irrigation techniques for the soybean-rice rotation; assist the Mississippi Department of Environmental Quality and the Yazoo Mississippi Joint Delta Water Management District by providing practical, field-tested irrigation practices; and reduce non-point source runoff of agrichemicals into nearby surface waters while reducing carbon emissions related to energy use. Finally, the results of this research will produce educational materials for producers on water-efficient cropping systems.

Characterization of PCP Degrading Enzymes through Gene Expression Analysis During Biosparging of Contaminated Groundwater

M. Lynn Prewitt, Hamid Borazjani and Susan V. Diehl, Department of Forest Products, Mississippi State University

Groundwater quality is an important issue that affects not only the health and well being of all living things but also the economic growth and development of the state and region. Since most of Mississippi's water supply is from groundwater, a need for comprehensive monitoring of groundwater contamination is needed. Reports indicate that 10 percent of rural domestic wells contain at least one pesticide or pesticide metabolite. One of the pesticides found in groundwater in the Mississippi Delta region is Pentachlorophenol, also known as PCP. PCP is an organochlorine compound which has been used as a herbicide, insecticide, fungicide, algaecide, disinfectant and as an ingredient in some paints. It is highly toxic and difficult to degrade in nature and becomes a problem to living organisms when found in groundwater. PCP contaminated groundwater is caused predominately by agricultural runoff and improper disposal at wood treating facilities.

A new study in the Institute is working to identify the enzymes produced by the indigenous bacteria that degrades PCP in contaminated groundwater. The identity of the PCP degrading enzymes will be determined through gene expression analysis of bacterial cDNA. To identify the enzymes, scientists will use biosparging bioremediation—a process where air and nutrients are injected into the contaminated water to increase the biological activity of indigenous microorganisms. Nutrients will be added on a monthly basis and bacterial populations will be monitored. The results will help to reveal the mechanism by which this bacterial community degrades PCP and to determine if enzymes critical to PCP degradation are present. Biological consortiums can be developed to produce all enzymes which are needed to more effectively degrade PCP in contaminated groundwater to levels below detectable limits.

Sources, Sinks, and Yield of Organic Constituents in Managed Headwaters of the Upper Gulf Coastal Plain of Mississippi

Jeff A. Hatten, Janet C. Dewey, and Andrew W. Ezell, Forestry, Mississippi State University

Forest management activities can potentially affect 20 million acres in Mississippi, much of which is in headwater catchments. Headwater streams contribute water and nutrients to downstream fluvial environments, however the sediment, organic matter, and nutrients (particularly nitrogen) from these streams most often lead to the impaired designation for rivers in Mississippi. Many studies of non-mountainous systems have focused on the quantity of particulate or dissolved forms of material, however, few have examined the source of this material. This research will address the transport and source/sink behavior of sediment and both dissolved and particulate forms of organic matter in the form of nitrogen (N) and organic carbon, over a range of hydrographic conditions and scales. The objective is to quantify the yield, source, and transport processes of organic carbon and nutrients within managed, forested watersheds in Webster County, Mississippi.

Results from this research will be of value to forested-watershed managers as they weigh the environmental cost versus nutrient cycling benefit of organic inputs resulting from silvicultural activities.

MWRRI-funded Projects

A Climate-Driven Model to Serve as a Predictive Tool for Management of Groundwater Use from the Mississippi Delta Shallow Alluvial Aquifer

Charles L. Wax, Geosciences and Jonathan W. Pote, Agricultural and Bioengineering, Mississippi State University

The main source of groundwater in the Mississippi Delta region is the shallow alluvial aquifer. This aquifer is heavily used for irrigation of cotton, soybeans, corn; rice flooding; and filling aquaculture ponds in the catfish industry. The water volume in the aquifer is subject to seasonal declines and annual fluctuations caused by both climatological and crop water use variations from year-to-year. Some of the declines can be very dramatic during April–October each year but are heightened in years when normal crop demands are accentuated by concurrent abnormally dry climatic conditions. In many years, recharge during the remainder of the year is insufficient to return water volume back to a normal level.

Previous research performed by scientists in the Institute produced a model that illustrated a link in water management planning for the Mississippi Delta. From this model. the U.S. Geographical Survey has produced maps of the alluvial aquifer and descriptions of the

rate of change. The U.S. Army Corps of Engineers has used the data to develop river and lake descriptions and models. The Yazoo Mississippi Delta Joint Water Management District has collected a large amount of data on cropping, irrigation systems, and rate of water use for the locations which were used in the model. The Mississippi Department of Environmental Quality houses and uses these data also. Earlier studies linked changes in water use to weather data and this information was then linked to the aquifer levels. Historical weather records were then used to predict the long-term impacts of land use changes on aquifer levels. Our current understanding of how weather and irrigation interact to influence aquifer levels is missing the ability to predict how a crop management change will impact changes in the aquifer. This model is being developed to address this need. This research will further develop and refine the model as a tool for management decisions and water conservation throughout the Delta region. Objectives are to improve the rainfall-irrigation use relationship; expand the model for the entire Delta region; and attempt to determine a more realistic recharge amount for the aquifer every year, which will illustrate accuracy of the model results.

The spreadsheet simulation model, when complete, will become a tool that can easily be modified as new information becomes available. This will become useful in making management decisions that will allow sustainable use of the groundwater resource.

Economic Development

Support for a Northeast MS Regional Water Management Plan

Mary Love Tagert, Mississippi Water Resources Research Institute

Adequate water and wastewater infrastructure are important for promoting economic development, maintaining public health, and protecting the environment. The Tombigbee River Valley Water Management District (TRVWMD) recognized the vital role of infrastructure and water supply issues in the future of Northeast Mississippi. The district recently created two new multi-county water and wastewater districts within their twelve member counties. One step in the formation of these new districts is the creation of a water management plan for the area. The TRVWMD requested the Institute's assistance in organizing and drafting a water management plan for Itawamba, Prentiss, and Tishomingo Counties to better prepare these counties for future economic development opportunities. A series of public meetings was held in Northeast Mississippi to discuss the contents of the plan and request input and assistance from regional and local stakeholders. A final draft assessing the current surface and groundwater resources, the demand on these resources, and projected future needs has now been completed and submitted to the water district. While there are currently sufficient water resources to meet the needs of these three counties, if two or more large industrial development projects materialize at once or if the population grows more rapidly than anticipated, these counties will undoubtedly have a greater demand on their current water resources. The water management plan and the efforts of the district to establish a new multi-county water and wastewater region move the area a step closer in proactively planning for future water supply and infrastructure needs. With growing concern over long-term water availability in the Southeastern region and the increase in new development projects locating in Northeast Mississippi, regional water and wastewater organizations will be critical in planning for future needs.

Economic Development

Grenada County Economic Development Project

Mary Love Tagert, Mississippi Water Resources Research Institute; Jon Rezek and Ben Blair, Finance and Economics; Wayne Wilkerson, Landscape Architecture, Mississippi State University

Grenada Lake encompasses over 35,000 acres of water and welcomes some 2 million visitors annually. The U.S. Army Corps of Engineers lake began in 1954 to help control flooding in the Yazoo River Basin. The lake generates about $42 million in visitor spending each year, according to the U.S. Army Corps of Engineers. While the impact of the lake and facilities is significant to the surrounding area, the Grenada Chamber of Commerce is seeking to increase these numbers. The Chamber contacted the Mississippi Water Resources Research Institute for assistance in promoting economic development around the lake. The multi-use facility is managed by the Corps' Vicksburg District not only for flood control, but also for public recreation, conservation of fish and wildlife, and public forests. Grenada Lake is also home to Hugh White State Park and a recently constructed 18-hole golf course. The Chamber sought help in working with the Corps to promote economic development based on the lake's numerous recreational opportunities and bountiful natural resources. Institute staff and faculty in Mississippi State's departments of landscape architecture and finance and economics have developed a master plan for the area currently occupied by the Hugh White State Park. The master plan, along with marketing and economic feasibility studies have been presented at a public forum in Grenada.

Southeastern Regional Small Public Water Systems Technical Assistance Center (SE-TAC)

Mary Love Tagert, Mississippi Water Resources Research Institute; Jonathan Pote, Department of Agricultural and Biological Engineering, Mississippi State University

The Southeastern Regional Small Public Water Systems Technical Assistance Center (SE-TAC), funded by the Environmental Protection Agency, was established in 2000 as part of EPA's Technical Assistance Center Network authorized by the Safe Drinking Water Act (SDWA) amendments of 1996 and has been administered by Mississippi State University since its inception. SE-TAC's mission is to build partnerships among water utility organizations, state primacy agencies, technical assistance providers, and universities throughout the Southeastern Region of the United States to protect public health by enhancing small water systems' capacity to protect and provide safe drinking water. SE-TAC works closely with state and regional organizations and agencies to assist small public water systems in acquiring and maintaining the technical, financial, and managerial capacity to provide safe drinking water and meet the SDWA's public health protection goals. SE-TAC's efforts are focused on eleven states in the Southeastern United States: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee and Texas. A multi-state, fifteen member, external Advisory Board helps SE-TAC avoid duplication of effort and focus the program's resources on issues inadequately addressed by existing programs. SE-TAC provides a forum to create partnerships that can identify gaps in existing capacity development programs. Since its establishment, SE-TAC has provided a competitive grants program to develop novel pilot projects to fill those gaps and directly assist small drinking water systems in protecting human health and complying with the SDWA's increased technical, monitoring, and reporting requirements. Competitively-funded projects currently underway include:

- Asset Management, Board Training, and Capacity Development for Small Drinking Water Systems, Florida Rural Water Association
- Developing Workforce Strategies to Meet Utility Employment Needs, Alabama Rural Water Association.

More recently, SE-TAC has also incorporated an applied approach to directly and meaningfully provide asset management and mapping assistance for small public water systems in the region, with efforts in the current funding cycle focused on Northeast Mississippi.

Hundreds of small public water systems have received training and assistance with technical, financial and managerial issues through SE-TAC projects, as all projects and outputs have the goal of transferability to other small systems.

Publications

Choi, B., A.W. Ezell, J.C. Dewey. 2009. Headwater hydrologic functions in the Upper Gulf Coastal Plain of Mississippi. Page 124 in Proceedings, Mississippi Water Resources Conference.

Dewey, J.C., A.W. Ezell, J.O Palmer, B. Choi. 2009. Possible correlations among simple visual disturbance estimates and hydrologic and edaphic parameters in forested headwaters of Mississippi. Page 14 in Proceedings, Mississippi Water Resources Conference.

Dyer, J.L. 2009. Evaluation of surface and radar estimated precipitation data sources over the Lower Mississippi River Alluvial Plain. Physical Geography 30:430-452.

Dyer, J.L. 2009. Influences of land surface characteristics on precipitation over the Lower Mississippi Alluvial Plain. Pages 54-67 in Proceedings, 2009 Mississippi Water Resources Conference.

Kinnaman, A. 2009. The use of microcosm studies to determine the effect of sediments and nutrients on bacteria in lake water. Thesis, Department of Environmental Engineering, University of Mississippi. 105 pgs.

Kinnaman, A., C.Q. Surbeck. 2009. The use of microcosm studies to determine the effect of sediments and nutrients on fecal indicator bacteria in lake water. Page 130 in Proceedings, Mississippi Water Resources Conference.

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Schmidt, J., K.A. Brasher. 2009. Mississippi Water Resources Annual Report.

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Stokes, C.E., M.L. Prewitt, H. Borazjani. 2009. Molecular identification of pentachlorophenol (PCP) tolerant bacterial communities in contaminated groundwater. Page 22 in Proceedings, Mississippi Water Resources Conference.

Surbeck, C.Q. 2009. Monitoring and statistical analysis of fecal indicator bacteria in Lower Sardis Lake, Mississippi. Page 148 in Proceedings, Mississippi Water Resources Conference.

Tagert, M.L.M. 2009. Support for a Northeast Mississippi regional water management plan. Page 172 in Proceedings, Mississippi Water Resources Conference.

Wax, C.L., J.W. Pote, T.L. Merrell. 2009. Climatological and cultural influences on the potential for conservation of groundwater in the Mississippi Delta shallow alluvial aquifer by substituting surface water for irrigation. Pages 68-81 in Proceedings, Mississippi Water Resources Conference.

Advisory Board

Cooperators

City of Bay St. Louis, Mississippi

Environmental Protection Agency, Office of Ground Water and Drinking Water

Grenada County Chamber of Commerce

Mississippi Department of Environmental Quality

Pearl River Valley Water Supply District

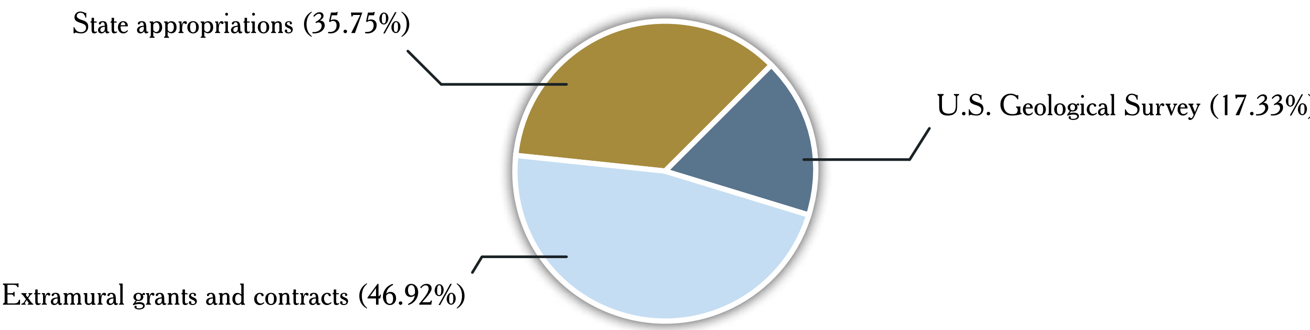
Pickering, Inc.

Tombigbee River Valley Water Management District

U. S. Geological Survey

Financial Summary

Program Component	Federal	Non-Federal	Total
U.S. Geological Survey grant	$92,335		$92,335
State appropriations		$190,449	$190,449
Extramural grants and contracts		$250,000	$250,000
TOTAL	$92,335	$440,449	$532,784



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MISSISSIPPI STATE UNIVERSITY

College of Forest Resources

Forest and Wildlife Research Center

Information Transfer Program-Conferences

Basic Information

Title:	Information Transfer Program-Conferences
Project Number:	2010MS156B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	3rd
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	, George M. Hopper

Publications

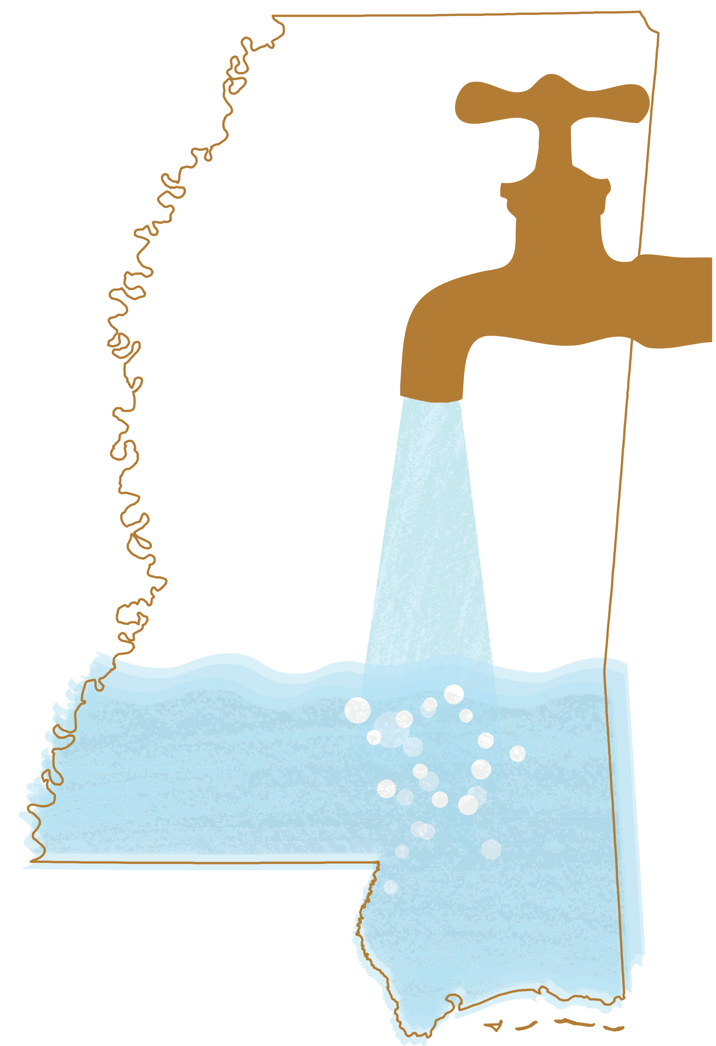
1. 2010, Mississippi Water Resources Conference Program and Abstracts, Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 12 pgs.
2. 2011, Mississippi Water Resources Conference Proceedings, Mississippi Water Resources Research Institute, Mississippi State University, Mississippi State, MS, 185 pgs., www.wrri.msstate.edu/pdf/2010_wrri_proceedings.pdf

2010

Mississippi Water Resources Conference

Hollywood Casino

Bay St. Louis, MS



EXHIBITORS:

Northern Gulf Institute
Pickering, Inc.
U.S. Army Corps of Engineers

SPONSORS:

Florence and Hutcheson
Neel Schaeffer
Rosedale-Bolivar Port
Waggoner Engineering

CONFERENCE ORGANIZERS:

Mississippi Department of Environmental Quality | Mississippi Water Resources Association | Mississippi Water Resources Research Institute
National Oceanic and Atmospheric Administration | U.S. Geological Survey

November 3 Wednesday

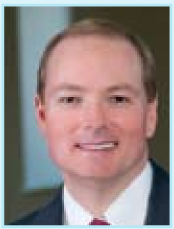
7:15 a.m. **Registration and Continental Breakfast**

8:00 a.m. **PLENARY SESSION** *(Moderator: George M. Hopper, Mississippi Water Resources Research Institute)*

Mark Keenum
Mississippi State University
Mississippi Water Resources Issues and Opportunities

William Walker
Mississippi Department of Marine Resources
The Gulf of Mexico Alliance and the Deepwater Horizon Oil Spill

Russ Beard
National Oceanic and Atmospheric Administration
The Federal Joint Analysis Group: NOAA's Response to the Deepwater Horizon Oil Spill



MARK KEENUM

In 2009, Mark Keenum became Mississippi State's 19th president, following a distinguished public service career. Keenum joined the staff of U.S. Senator Thad Cochran in 1989 as Legislative Assistant for Agriculture and Natural Resources. From 1996-2006, he served as Chief of Staff for Sen. Cochran. Keenum also served as Under Secretary of the U.S. Department of Agriculture from 2006-2008. Prior to his public service career, Keenum worked at Mississippi State University as a marketing specialist for the Extension Service, a research associate with the Mississippi Agricultural and Forestry Experiment Station, and as an assistant professor in agricultural economics. Keenum received his bachelor's, master's, and doctoral degrees in Agricultural Economics from Mississippi State University.

WILLIAM WALKER

William Walker was appointed in 2002 as Executive Director of the Mississippi Department of Marine Resources. Prior to his appointment to the state agency, he was employed by the U.S. Environmental Protection Agency and was serving as a Legislative Fellow in the Office of Sen. Trent Lott. Walker completed a 28-year career at the University of Southern Mississippi—Gulf Coast Research Laboratory where he served as Associate Director and was instrumental in building a variety of environmental toxicology programs. Walker received his bachelor's degree in Botany and Microbiology from Southeastern Louisiana University and his master's and doctoral degrees in Soil Microbiology and Biochemistry from Mississippi State University.

RUSS BEARD

Russell H. Beard was selected Director of the National Oceanic and Atmospheric Administration's National Coastal Data Development Center in 2007. He previously served as Chief Scientist for NOAA for five years. Prior to joining NOAA, Beard was employed by the Naval Oceanographic Office for 15 years providing oceanographic support to the fleet, joint forces, and naval special warfare related to Intelligence, Surveillance and Reconnaissance. Beard received two bachelor degrees in History and Geology from Millsaps College, and a master's degree in Geology from the University of Southern Mississippi. Beard is a graduate of the U.S. Department of Agriculture Graduate School's Executive Potential Program for senior federal employees.

9:30 a.m. **POSTER SESSION**

Garry Brown *University of Mississippi*	Concentration of methylmercury in natural waters from Mississippi using a new automated analysis system
Pragya Chakravarty *University of Mississippi*	Mercury deposition in Northern Mississippi wetlands using sediment cores and thermal decomposition, amalgamation, and atomic absorption spectrometry
Nathan Clifton *Mississippi State University*	Regional sediment management plan
Gary N. Ervin *Mississippi State University*	Assessing early responses of natural coastal systems to oil and dispersant contamination along the Northern Gulf of Mexico
James A. Garner *Jackson State University*	Submerged aquatic vegetation communities of Mississippi coastal river systems
Shane Irvin *Mississippi State University*	Detecting water quality parameters in Tibbee Creek, Mississippi using aerial imagery
Robert Kröger *Mississippi State University*	A water quality perspective to evaluating the potential of reservoirs in Puerto Rico for sport fisheries management
Adam Lawson *Naval Research Laboratory*	Automated system to facilitate vicarious calibration of ocean color sensors
Christopher L. Martin *University of Southern Mississippi*	Relation between chromophoric dissolved organic matter (CDOM) and salinity in the Mississippi Sound
Sam Testa *USDA Agricultural Research Service*	Water quality and ecology research in the Mississippi Delta
K. Van Wilson *US Geological Survey*	Identification of streambank erosion processes and channel changes in Northeastern Mississippi
Alina Young *Mississippi State University*	Watershed characterization of the Big Sunflower watershed

9:45 a.m. **TECHNICAL PRESENTATIONS**

Session #1 - Sedimentation
Salon A
Moderator: Jim Shepard, Mississippi Water Resources Research Institute

Prem B. Parajuli *(Mississippi State University)* - Spatially distributed sediment and nutrients loading from the Upper Pearl River watershed

John J. Ramírez-Avila *(Mississippi State University)* - Rates and processes of streambank erosion along the principal channel of the Town Creek watershed: Implications in a sediment budget development

Jeff Hatten *(Mississippi State University)* - Sediment, particulate organic carbon, and particulate nitrogen transport in ephemeral and perennial streams of the upper coastal plain Mississippi

Daniel G. Wren *(USDA ARS National Sedimentation Laboratory)* - Using lake sedimentation rates to quantify the effectiveness of past erosion control in watersheds

Matthew Hicks *(U.S. Geological Survey)* - Mill Creek watershed restoration: Results of monitoring sediment concentration and loads pre- and post-BMP implementation

Session #2 - Weather/Climate
Salon B
Moderator: Jamie Dyer, Mississippi State University Department of Geosciences

Kai Roth *(National Weather Service)* - New modeling system at the Lower Mississippi River Forecast Center

Thewodros G. Mamo *(Polytechnic Institute of New York University)* - Adaptation to rainfall variation considering climate change for the planning and design of urban stormwater drainage networks

Jamie Dyer *(Mississippi State University)* - Effect of land cover boundaries on warm-season precipitation generation in Northwest Mississippi

Katelyn E. Costanza *(National Weather Service)* - Flash flood guidance issued by the National Weather Service—past, present, future

Session #3 - Coastal Resources
Salon C
Moderator: Mary Love Tagert, Mississippi Water Resources Research Institute

William H. McAnally *(Mississippi State University)* - Oil spill assessment: Transport and fate

Matthew Dornback *(University of Southern Mississippi)* - Phytoplankton biomass variability in a western Mississippi Sound time-series

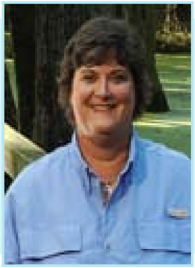
Rene Alexander Comacho *(Mississippi State University)* - Evaluation of the estuarine retention time in a Mississippi estuary: The Bay of St. Louis

Scott P. Milroy *(University of Southern Mississippi)* - Three-dimensional heterogeneity of hypoxic water masses in the Mississippi Sound: The geomorphology connection

Mary Love M. Tagert *(Mississippi State University)* - Asset management assistance for the city of Bay St. Louis

11:45 a.m. **LUNCH AND KEYNOTE ADDRESS** *(Moderator: Jamie Crawford, Mississippi Department of Environmental Quality)*

Trudy Fisher *Mississippi Department of Environmental Quality*



TRUDY FISHER

Trudy Fisher was appointed Executive Director of the Mississippi Department of Environmental Quality in 2007. Prior to her appointment, she was a partner with the Jackson-based Brunini, Grantham, Grower & Hewes law firm. She previously served as the Mississippi Department of Environmental Quality's General Counsel. Fisher earned a bachelor's degree from the Mississippi University for Women and a juris doctor degree from the University of Mississippi School of Law, where she served as editor-in-chief of the Mississippi Law Journal.

1:30 p.m. **Technical Presentations**

Session #4 - Surface Water Management
Salon A
Moderator: Robert Kröger, Mississippi State University Department of Wildlife, Fisheries, and Aquaculture

David R. Johnson *(US Army Corps of Engineers)* - Delta headwaters project—Boon or bust to water quality?

Robert Kröger *(Mississippi State University)* - What do we know about field scale nutrient reductions of instream practices in the Mississippi Delta?

John J. Ramírez-Avila *(Mississippi State University)* - Evaluation of two different widths of vegetative filter strips to reduce sediment and nutrient concentrations in runoff from agricultural fields

Session #5 - Wetlands
Salon B
Moderator: Jim Shepard, Mississippi Water Resources Research Institute

Michael Rasmussen *(University of Southern Mississippi)* - Environmental mitigation at the Camp Shelby Training Site, MS

Cristina Nica *(Jackson State University)* - Study of seagrass beds at Grand Bay National Estuarine Research Reserve

Amy B. Spencer *(Mississippi State University)* - Ecosystem services from moist-soil wetland management

Track #6 - Education
Salon C
Moderator: Lynn Prewitt, Mississippi State University Department of Forest Products

Robert F. Brzuszek *(Mississippi State University)*- The Sustainable Sites Initiative™: Potential impacts for water resources and site development

Renee M. Clary *(Mississippi State University)* - The future of K-12 water education: The 2010 Mississippi framework and the proposed National Research Council framework for science education

Joy Buck *(University of Southern Mississippi)* - The Chickasawhay River: A small Mississippi stream vs. the U.S. Army Corps of Engineers

November 3 Wednesday

2:45 p.m. **Break and Poster/Exhibitor Viewing**

3:00 p.m. **MWRA Board Meeting** (Magnolia Room)

3:00 p.m. **TECHNICAL PRESENTATIONS**

Session #7 - Management/Planning
Salon A
Moderator: Jason Barrett, Mississippi State University Extension Service

Michael E. Stovall *(University of Alabama)* - Sustaining Alabama fishery resources: A risk-based integrated environmental, economic, and social resource management decision framework

C. Elizabeth Stokes *(Mississippi State University)* - Identification of pentachlorophenol tolerant bacterial communities in contaminated groundwater after air-sparging remediation

Jason Barrett *(Mississippi State University)* - The influences on the capacity development assessment scores of publicly-owned drinking water systems in Mississippi

Session #8 - Wetlands
Salon B
Moderator: Jim Shepard, Mississippi Water Resources Research Institute

Thomas H. Orsi *(University of Southern Mississippi)* - Use and effectiveness of natural remediation of wetlands at the GV Sonny Montgomery Multi-Purpose Range Complex–Heavy (MPRC-H), Camp Shelby Joint Forces Training Center (CSJFTC), MS

Timothy J. Schauwecker *(Mississippi State University)* - Developing a gum swamp educational exhibit at the Crosby Arboretum, Mississippi State University Extension

Mary Catherine Mills *(Mississippi State University)* - Evaluating physiological and growth responses of *Arundinaria* spp. to inundation

Session #9 - Delta Groundwater
Salon C
Moderator: Jamie Crawford, Mississippi Department of Environmental Quality

Charles L. Wax *(Mississippi State University)* - Refining effective precipitation estimates for a model simulating conservation of groundwater in the Mississippi Delta Shallow Alluvial Aquifer

Jeannie R.B. Barlow *(U.S. Geological Survey)* - Water use conservation scenarios for the Mississippi Delta using an existing regional groundwater flow model

Joseph H. Massey *(Mississippi State University)* - Water-conserving irrigation systems for furrow and flood irrigated crops in the Mississippi Delta

Heather L. Welch *(U.S. Geological Survey)* - Dissolved phosphorus concentrations in the Mississippi River Valley Alluvial Aquifer, Northwestern Mississippi

5:00 p.m. **Welcome Reception and Poster/Exhibitor Viewing**

November 4 Thursday

7:15 a.m. **Registration, Continental Breakfast, and Poster/Exhibitor Viewing**

8:00 a.m. **TECHNICAL PRESENTATIONS**

Session #10 - Nutrients
Salon A
Moderator: Jim Shepard, Mississippi Water Resources Research Institute

Matt Moran *(Mississippi State University)* - Nutrient modeling of the Big Sunflower Watershed

Matthew Hicks *(U.S. Geological Survey)* - Plan for monitoring success of Mississippi's Delta nutrient reduction strategy

Marcia Woods *(Jackson State University)* - The fate and transport of nitrate in the surface waters of the Big Sunflower River in Northwest Mississippi

Session #11 - Delta Water Resources
Salon B
Moderator: Mickey Plunkett, U.S. Geological Survey

Charlotte Bryant Byrd *(Mississippi Department of Environmental Quality)* - Evolution of surface water quantity issues in the Mississippi Delta

Richard H. Coupe *(U.S. Geological Survey)* - Effects of the BioFuels Initiative on water quality and quantity in the Mississippi Alluvial Plain

Claire Rose *(U.S. Geological Survey)* - Quantification of groundwater contributions to the Bogue Phalia in northwestern Mississippi using an end-member mixing analysis

Pat Mason *(Mississippi Department of Environmental Quality)* - Water supply in the Mississippi Delta: What the model has to say

Session #12 - Ports
Salon C
Moderator: Dean Pennington, Mississippi Water Resources Association

Jack Norris
Gulf Coast Business Council, Gulfport, MS

James Murphy
U.S. Dept. of Transportation, Maritime Administration, New Orleans, LA
America's Marine Highways

Joe Conn
Mississippi State Port Authority, Gulfport, MS
Restoration of the Port of Gulfport

9:30 a.m. **Break and Poster/Exhibitor Viewing**

9:45 a.m. **PLENARY SESSION** *(Moderator: Deirdre McGowan, Mississippi Water Resources Association)*

Colonel Jeffery Eckstein *U.S. Army Corps of Engineers, Vicksburg*	
Colonel Edward Fleming *U.S. Army Corps of Engineers, New Orleans*	Mississippi River and Louisiana Coast
Chief Thomas Minyard *U.S. Army Corps of Engineers, Memphis*	Memphis District 2010 and Beyond
Susan Rees *U.S. Army Corps of Engineers, Mobile*	Mississippi Coastal Improvements Program - A Comprehensive Plan for Coastal Resilience

COLONEL JEFFERY ECKSTEIN

Colonel Jeffrey R. Eckstein is Commander and District Engineer for the U.S. Army Corps of Engineers, Vicksburg District. Prior to taking the command in 2009, he served in several key positions including the execution of construction missions throughout Northern Iraq. He received a bachelor's degree in Civil Engineering from the United State Military Academy and a master's in Civil Engineering from the University of Washington. He is a registered professional engineer in Florida and Virginia.

COLONEL EDWARD FLEMING

Colonel Ed Fleming became the New Orleans District's 61st commander and district engineer in July, 2010. In this capacity, Fleming manages the Protection and Restoration Office, a component in New Orleans' effort to reduce risk for South Louisiana by executing comprehensive and integrated flood control. Fleming received a bachelor's degree in Civil Engineering Management from the U.S Military Academy, a master's degree in Environmental Engineering from the University of Maryland, and a second master's degree in National Security and Strategic Studies from the National War College.

CHIEF THOMAS MINYARD

Thomas Minyard is Chief, Engineering and Construction Division for the Memphis District, U.S. Army Corps of Engineers. Prior to joining the Corps in 1983, Minyard worked as a Structural Engineer for Mississippi Power and Light. Minyard received a bachelor's and master's degree in Civil Engineering from Mississippi State University. He is a registered professional engineer in the state of Mississippi and a member of the Society of American Military Engineers.

SUSAN REES

Susan Rees serves as Program Manager, Mississippi Coastal Improvements Program, Planning and Environmental Division of the U.S. Army Corps of Engineer. She has served in the Corps since 1981 in various duties including Coastal Environment Team Leader/Lead Oceanographer and Program Manager for the Northern Gulf of Mexico Regional Sediment Management Program. Rees received a bachelor's degree in Biology from the College of Charleston, and master's and doctoral degrees from the University of South Carolina.

November 4 Thursday

11:55 a.m. **LUNCH AND KEYNOTE ADDRESS** *(Moderator: George M. Hopper, Mississippi Water Resources Research Institute)*
Major General Michael Walsh *U.S. Army Corps of Engineers*
America's Watershed: A 200-year Vision

AWARDS PRESENTATION

MAJOR GENERAL MICHAEL WALSH
Major General Michael J. Walsh assumed command of the Mississippi Valley Division, Vicksburg in 2008. He also serves as President-designee of the Mississippi River Commission. Walsh came to the division from Baghdad, Iraq, where he was the Commander for the Corps Gulf Region Division. Walsh received a bachelor's degree in Civil Engineering from Polytechnic Institute of New York and a master's degree in Construction Management from the University of Florida.

1:30 p.m. **Tour of the Port of Gulfport**

1:30 p.m. **Golf Tournament**

November 5 Friday

8:00 a.m. **MWRA General Membership Breakfast Meeting**
(Moderator: Dean Pennington, Mississippi Water Resources Association)

Notes

Proceedings from this conference and past water resources conferences are available online at

www.wrri.msstate.edu

MISSISSIPPI
WATER RESOURCES
RESEARCH INSTITUTE

MISSISSIPPI STATE
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USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	16	0	0	0	16
Masters	14	0	0	0	14
Ph.D.	6	0	0	0	6
Post-Doc.	0	0	0	0	0
Total	36	0	0	0	36

Notable Awards and Achievements